A course in Quantum Computing: Introduction

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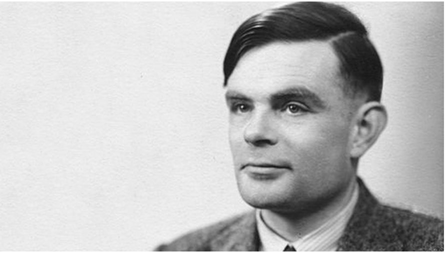
The subject

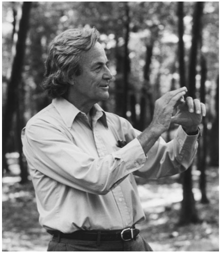
Alan Turing (1912 - 1934)



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)

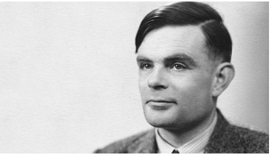
Quantum theory, the Church-Turing principle and the universal quantum computer (1985)
(quantum computability and computational model:
first example of a quantum algorithm that is exponentially faster than any possible deterministic classical one)

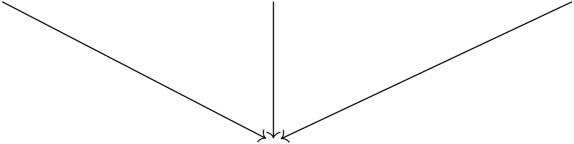
The subject

quantum resources

quantum algorithms

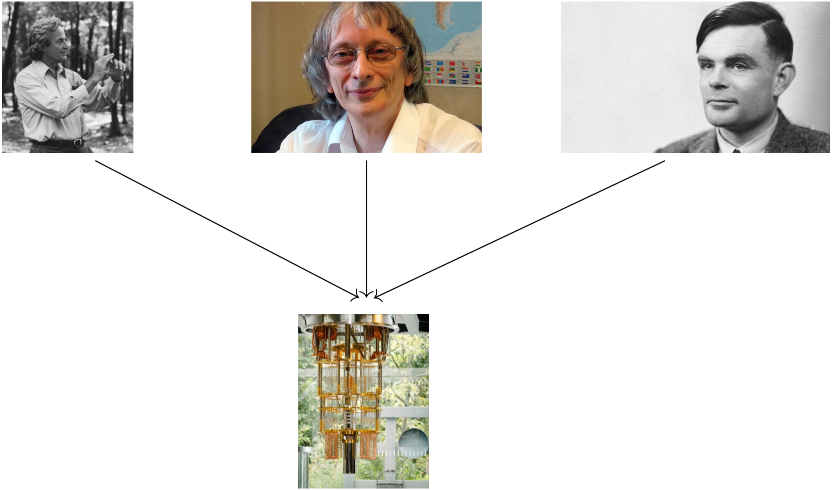
computability





The subject

quantum resources *quantum algorithms* *computability*

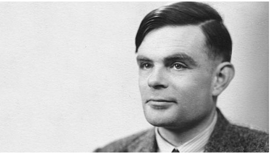


The subject

quantum resources

quantum algorithms

computability



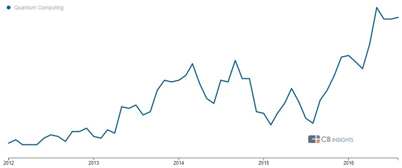
Quantum is trendy ...

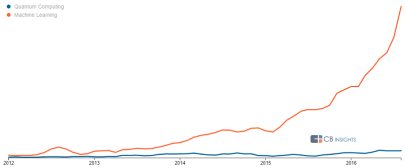
The second quantum revolution

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.

- huge investment by both the States, large companies and startups
- the race for quantum rising between major IT players (e.g. IBM, Intel, Google, Microsoft)
- proof-of-concept machines up to 50 qubits until the end of 2018
- national and regional programmes (from the 2016 Quantum Manifesto to the EU QT Flagship)

... but the race is just starting





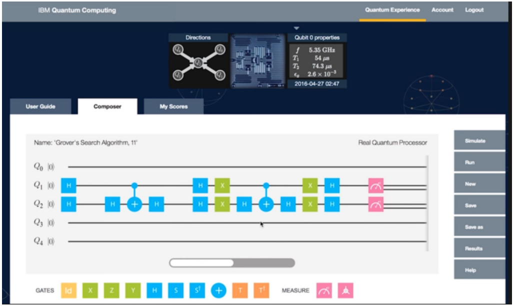
- Clearly, quantum computing will have a substantial impact on societies even if, being a so radically different technology,
- ... it is difficult to anticipate its evolution and future applications ...
- ... and its commercial potential in the near term (5 to 10 yrs) is still debatable

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 completions of the course students should be able

- To understand basic concepts of computability, computational complexity, and underlying mathematical structures;
- To master the principles and main techniques of quantum programming;
- To design and analyse quantum algorithms;
- To understand the basic elements of quantum programming languages and current implementations
- To implement and run quantum algorithms in the Qiskit open-source software development kit for IBM Q quantum processors.

Syllabus

1. Classical computational models, computability and complexity
2. Principles of quantum computation and programming
3. Quantum algorithms
4. Programming in Qiskit
5. Overview of quantum programming languages and quantum λ-calculus

Bibliography

Computability and Computational Complexity

1. H. R. Lewis and C. H. Papadimitriou. Elements of the Theory of Computation. Prentice Hall (2nd Edition), 1997.
2. S. Arora and B. Barak. Computational Complexity: A Modern Approach. Cambridge University Press, 2009.

Bibliography

Quantum Computation, Algorithms and Programming

1. M. A. Nielsen and I. L. Chuang. Quantum Computation and Quantum Information (10th Anniversary Edition). Cambridge University Press, 2010
2. N. S. Yanofsky and M. A. Mannucci. Quantum Computing for Computer Scientists. Cambridge University Press, 2008.
3. E. Rieffel and W. Polak. Quantum Computing: A Gentle Introduction. MIT Press, 2011.
4. R. S. Lipton and K. W. Regan.Quantum Algorithms via Linear Algebra: A Primer. MIT Press, 2014.
5. M. Ying. Foundations of Quantum Programming. Elsevier, 2016.

Bibliography

Bedtime readings

1. N. S. Yanofsky. The Outer Limits of Reason. MIT Press, 2013.
2. S. Aaronson. Quantum Computing since Democritus. Cambridge University Press, 2013.

Pragmatics

Assessment

- Training assignment (40%): 27 May
  (with intermediate ckeckpoints)
- Written test (60%): 27 May

Interaction

- web: `arca.di.uminho.pt/quantum-computation-1819/`
- contact: `lsb@di.uminho.pt`

Invitation to a fast running train ...

Academic IBM Q HUB since September, 1, 2018

- Part of the worldwide IBM Q Network of companies and academies to exploit potential applications of Quantum Computing in Industry
- Real time, full access to new quantum machines
- Multidisciplinar, dedicated teams
- A problem-driven research
- International cooperation