Quantum Computing

#SWFuturists

The power of quantum computing

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University of
BRISTOL

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EPSRC
Engineering and Physical Sciences
Research Council

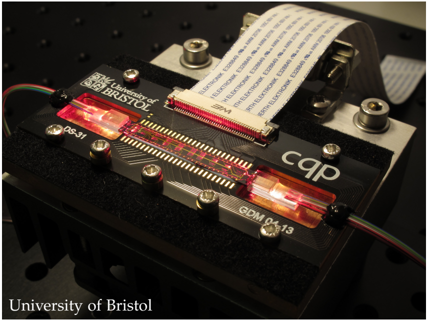
About me

My research tries to understand what quantum computers can do… and what they can't.

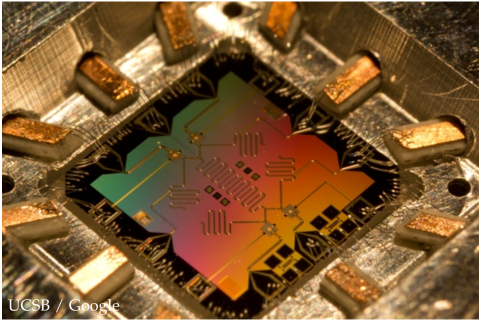
My background:

- 1998-2001: Undergraduate degree in Computer Science & Mathematics, Manchester
- 2001-2004: Software engineer working on mobile telephony
- 2004-2007: PhD in quantum computing, Bristol
- 2007-2013: Postdoctoral work in Bristol and Cambridge
- Now: Lecturer in Applied Mathematics and Research Fellow, University of Bristol

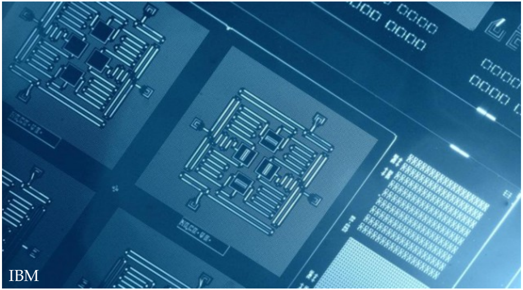
Quantum computers



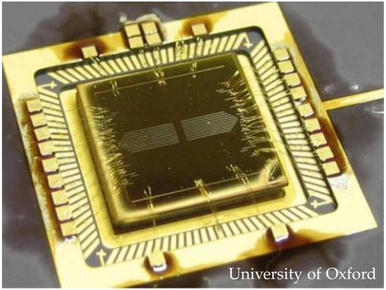
University of Bristol



UCSB / Google

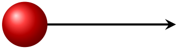


IBM



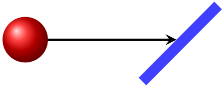
University of Oxford

Quantum mechanics



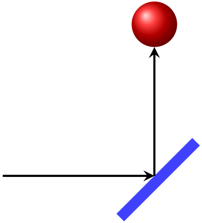
A simple example: the behaviour of a photon.

Quantum mechanics



When fired at a mirror, the photon bounces off.

Quantum mechanics



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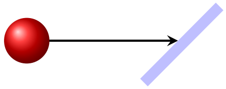
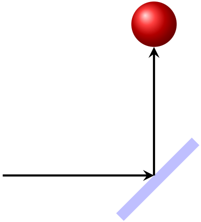


Now imagine we use a partly reflective mirror.

Quantum mechanics



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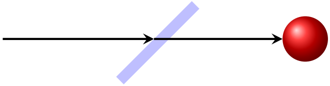

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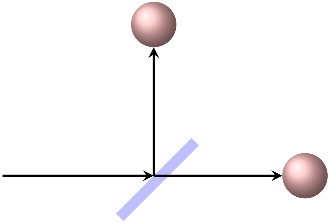
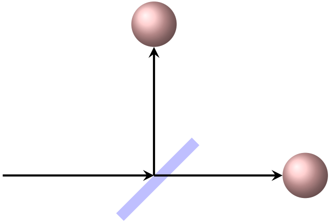


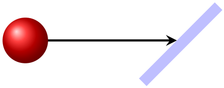
Then the photon is simultaneously reflected and transmitted!

Quantum mechanics



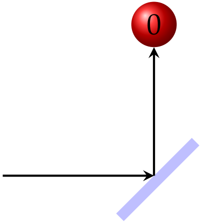
This phenomenon is known as superposition.

Quantum computing



Imagine the photon’s path encodes a bit of information.

Quantum computing



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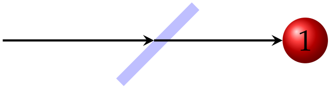

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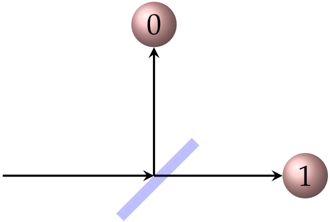
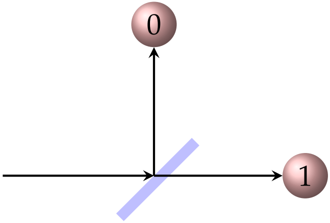


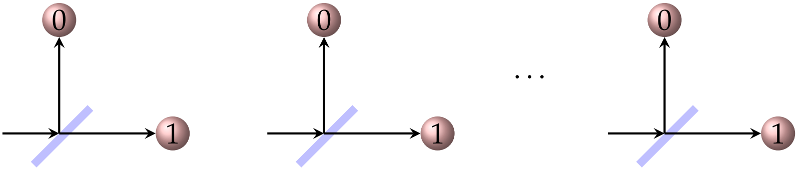
Then the photon’s state encodes a superposition of 0 and 1.

Quantum computing



This allows us to compute on input 0 and 1 simultaneously!

Quantum computing



If we have n photons, we have a superposition of 2^n states!

Key ingredients of quantum mechanics

1. Superposition. If a system can be in state A or state B, it can also be in a “mixture” of the two states. If we measure it, we see either A or B, with some probability of each.

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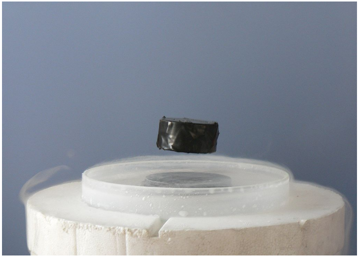
In quantum computing we use these effects to our advantage.

Simulation of quantum systems



Pics: Wikipedia

Integer factorisation

- Problem: Given an integer $N = p \times q$ for prime numbers p and q, determine p and q.

e.g. `43580844657661917011172827 4257`
= `940563886675753` × `46334805402 4169`

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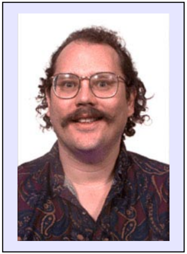


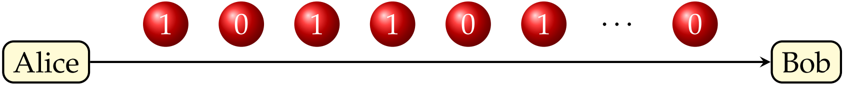
Pic: physik.uni-graz.at

A quantum algorithm due to Peter Shor solves this problem efficiently. No efficient classical algorithm is known.

Shor's algorithm breaks the RSA public-key cryptosystem on which Internet security is based.

Quantum cryptography

Conversely, quantum mechanics can be used to provide security guaranteed by the laws of physics.



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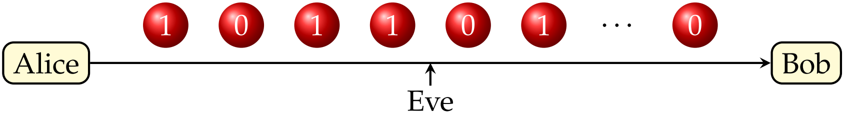

If an eavesdropper (Eve) attempts to read Alice’s communication to Bob, the disturbance she causes can be detected.

Quantum search and optimisation

One of the most basic problems in computer science: unstructured search.

- Imagine we have n boxes, each containing a 0 or a 1. We can look inside a box at a cost of one query.

- We want to find a box containing a 1.

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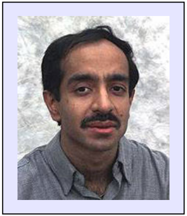

Pic: Bell Labs

A quantum algorithm due to Lov Grover can solve the search problem with roughly $\sqrt{n}$ quantum queries.

Many applications to practically important search and optimisation problems.

Summary

- Quantum computers allow fundamentally new modes of information processing and have many exciting applications.

- A large-scale, general-purpose quantum computer could have a huge impact on all of our lives.

- We don't have one yet… but people are working on it! (see next talk)

Further reading:
Quantum algorithms: an overview,
AM, *npj Quantum Information* 2, 2016
`www.nature.com/articles/npjqi201523`