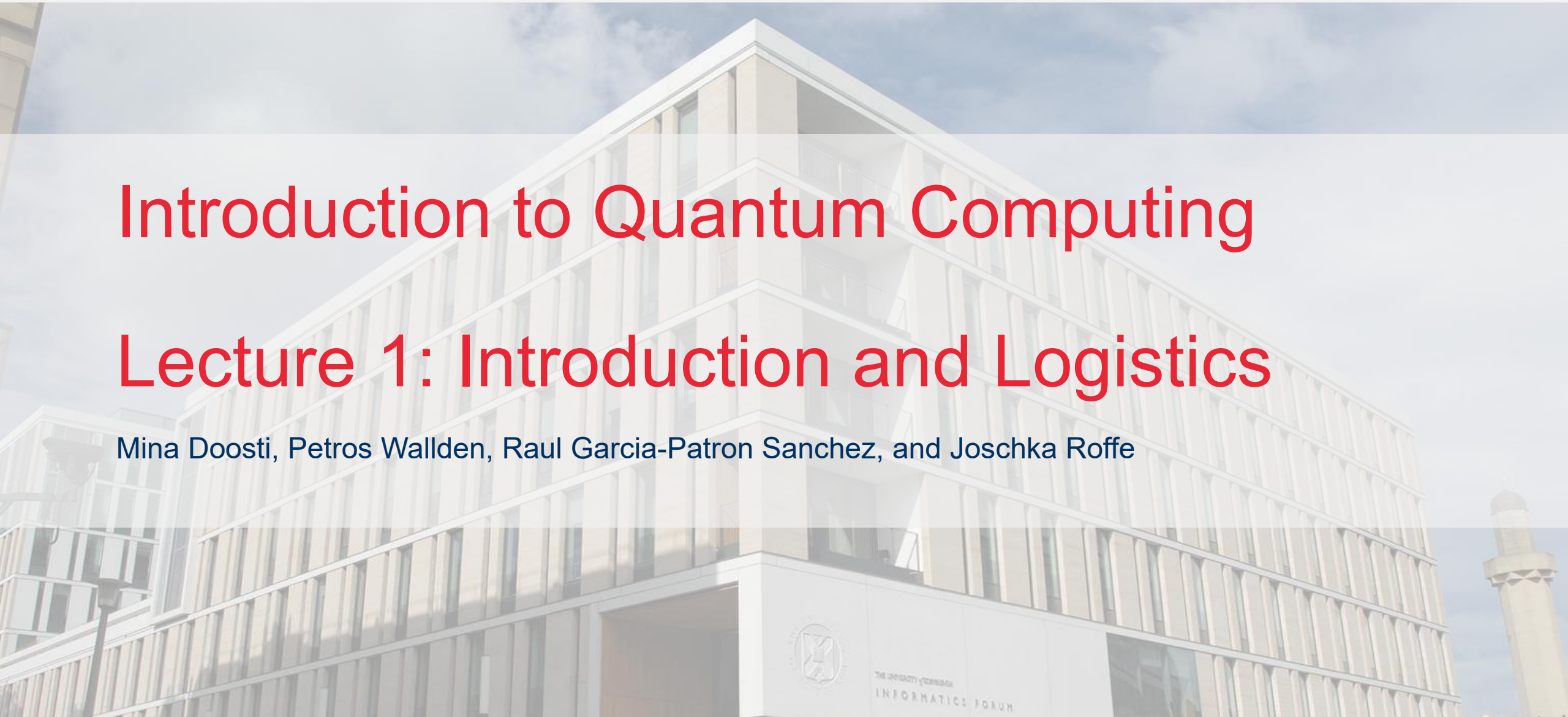


THE UNIVERSITY of EDINBURGH
informatics

Introduction to Quantum Computing

Lecture 1: Introduction and Logistics

Mina Doosti, Petros Wallden, Raul Garcia-Patron Sanchez, and Joschka Roffe

Contacts

- Mina Doosti (Lecturer CO)

Email: mdoosti@ed.ac.uk

- Petros Wallden (Lecturer)

Email: petros.wallden@ed.ac.uk

- Raul Garcia-Patron Sanchez (Lecturer)

Email: rgarcia3@ed.ac.uk

- Joschka Roffe (Lecturer)

Email: joschka.roffe@ed.ac.uk

- Chirag Wadhwa (TA)

Email: chirag.wadhwa@ed.ac.uk

- Discussions and Questions on **EdStem**

Structure of the course

Lectures

- Weeks 1 to 10
- Tuesday **10:00-10:50** @ LG.11 - 40 George Square Lower Teaching Hub
- Wednesday **13:10-14:00** @ G.159 - MacLaren Stuart Room - Old College
- Thursday **10:00-10:50** @ 2.13 - Geography (Old Infirmary)

Tutorial (start week 2)

- Tutorial 0 on week 2
- 8 tutorials in total: weeks 3 to 10 (last one is without tutorial groups)
- Group A01: Thursdays **11:10 - 12:00** - location: 2.12 - Appleton Tower – (Mina Doosti)
- Group A02: Thursdays **12:10 - 13:00** - location: 2.11 - Appleton Tower - (Maria Gragera Garces)

Q&A after any lecture

Assessment

- Coursework 25%
  - One assignment released week 6 on **30th October**
  - Due Friday **13th November** 12:00 (2-weeks for assignement)

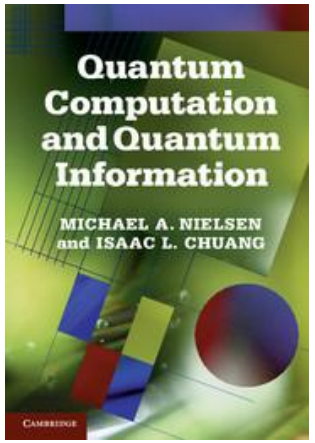
- Exam 75%
  - December
  - Revision session on week 10.

- Course is 20 credits since last year

Syllabus

- Intro to quantum mechanics and quantum circuits (6 lectures, Raul)
- Quantum algorithms: basic and FT (8 lectures, Raul)
- Quantum Programming: Pennylane (5 Lectures, Mina)
- Near-term quantum algorithms & quantum ML (3 lectures, Petros)
- Measurement-based quantum computation (3 lectures, Petros)
- Quantum error correction (3 lectures, Joschka)

Resources



- Quantum Computation and Quantum Information"
  by Michael A. Nielsen & Isaac L. Chuang

- Quantum Computing Lecture Notes
  by Ronald de Wolf
  https://arxiv.org/abs/1907.09415

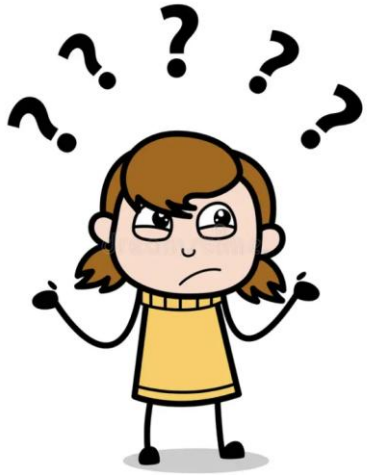
- Introduction to Quantum Computation
  Sevag Gharibian
  Lectures notes link

- Lecture Slides: https://opencourse.inf.ed.ac.uk/iqc/schedule
  Extra material/details given at the schedule
  Recordings from the Learn page of the course

Time to get excited!

So what’s this course about?

Ingredients for making a quantum scientists:



Confusion

Dream!

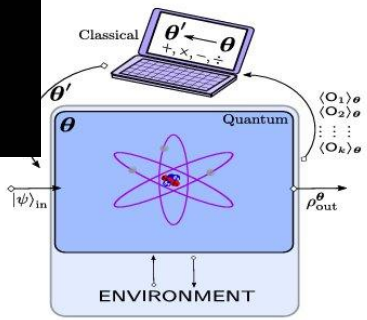
Nature is much weirder than we once thought!

How does it work? What does it mean?

Can we make this new weird nature to compute for us? Can we use it to communicate?

Quantum Science and Technology

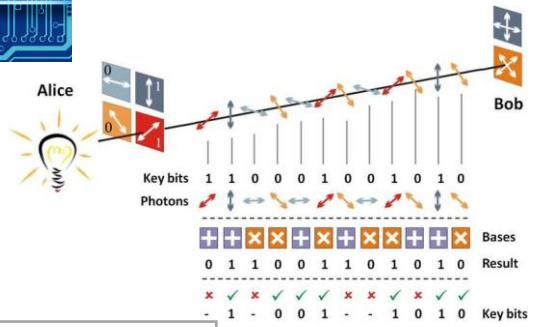
It's about learning a new paradigm for understanding "Information" and things we can do with it: Computation, Communication, Simulation…

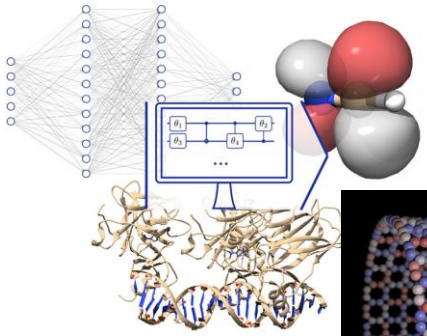


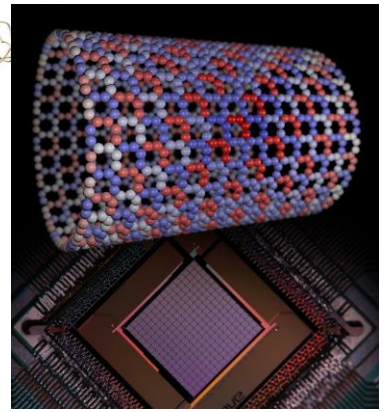
Quantum Computing

Quantum Machine Learning

Quantum Cryptography







Quantum Simulation (Applications in Physics, Chemistry and Material Science)

Quantum Information (MATH11169, Undergrad Math course)
Joan Simon Soler

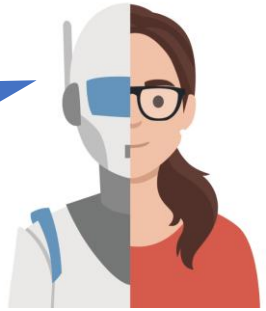
Quantum Cyber Security INFR11187 during S2
Me & Alexandru Cojocaru

Quantum Computing Project (PHYS10110 – Undergrad Phys course)
Steven Thomson

Why becoming a quantum scientist or engineer?

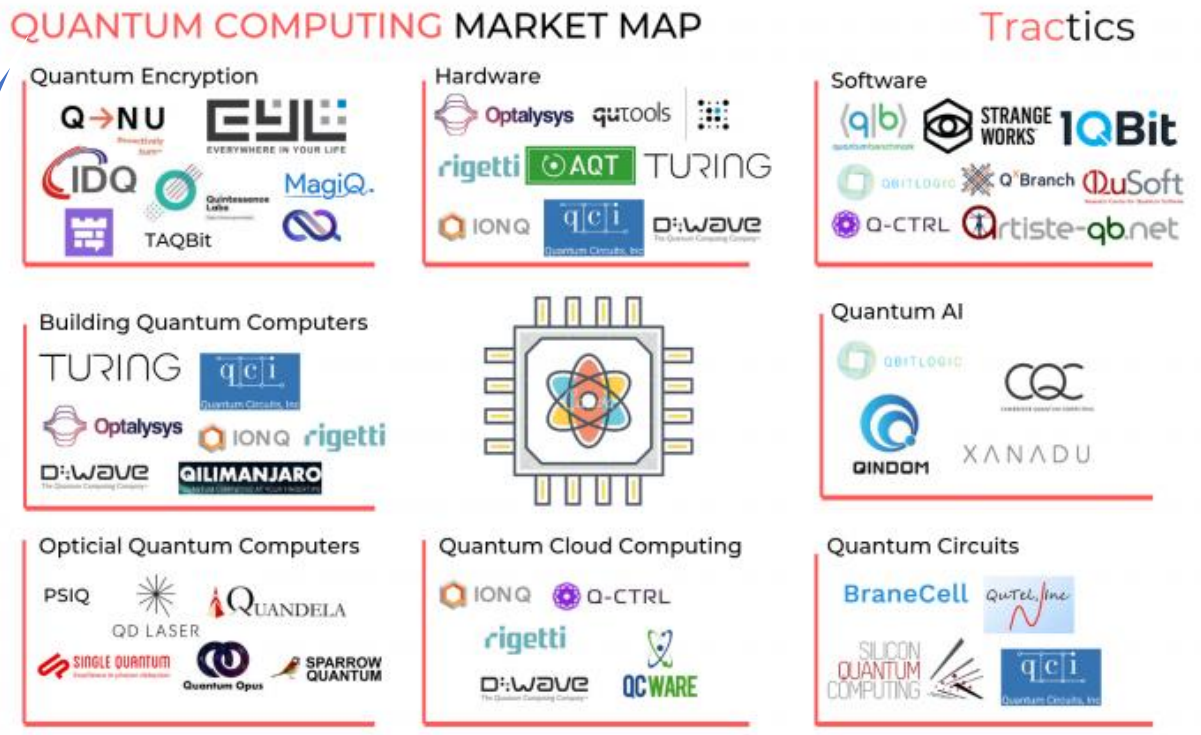
It's a field with still many deep and interesting questions, beautiful mathematics, and where you can be imaginative!

It's a very interdisciplinary field! It allows you to be able to think hybrid!



You can be part of creating something very cool and impactful for the future!

Exciting job market! Lots of companies and startups!



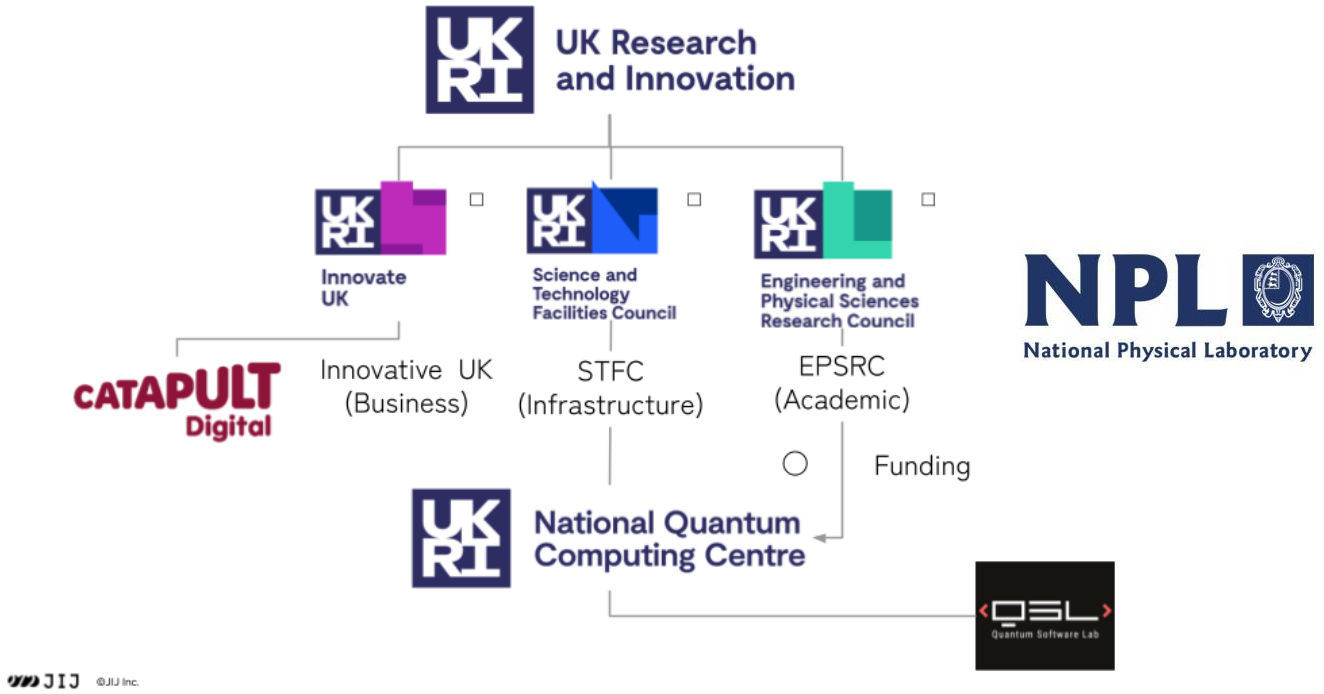
Where to find the quantum people in Edinburgh?

Quantum Software Lab

Many of us are in between Informatics Forum and Bayes Centre in the “quantum corridor”

The largest theory and application quantum group in the UK

Quantum Computing ecosystem in UK



Quantum Companies and startups

QUANTINUUM

Riverlane

PHASECRAFT

QUANTUM MOTION

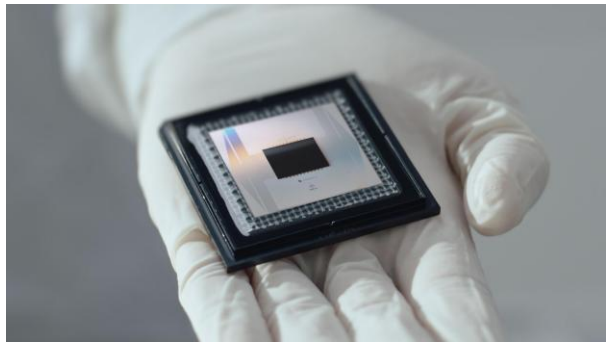
Oxford Ionics

nu QUANTUM

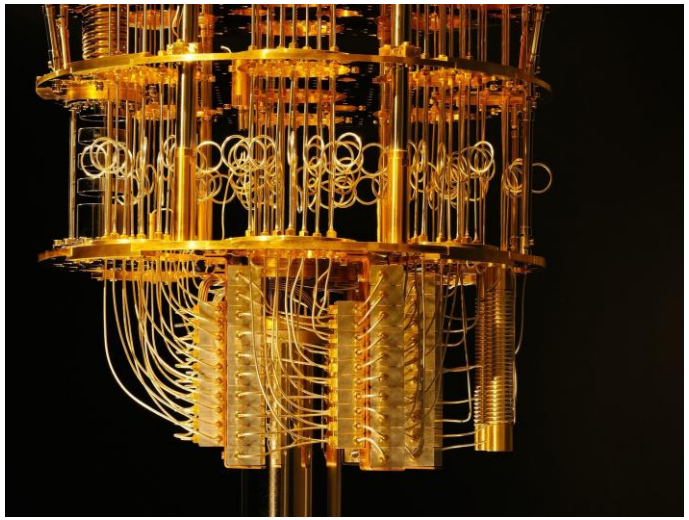
ORCA COMPUTING

PQ SHIELD

Quantum Computers Today



Google's Willow, 105 qubits



433-qubit IBM Quantum Osprey processor

QUANTINUUM

Helios 56 qubits

IONQ

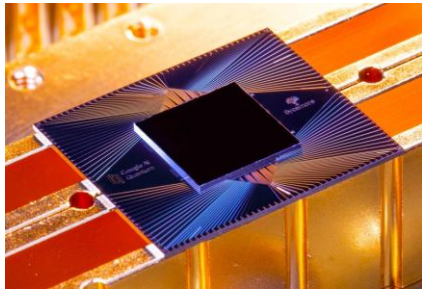
XANADU

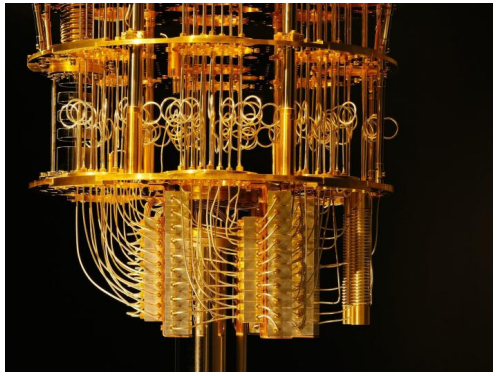
PsiQuantum

Different types of quantum hardware!
There are different things in nature with quantum behavior

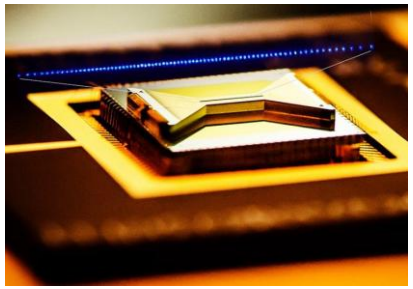
Hardware Architectures

Superconducting QPUs

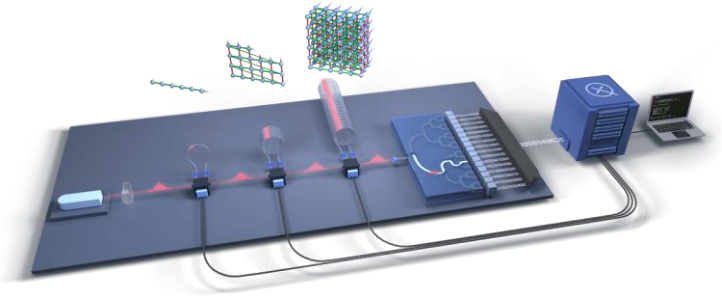




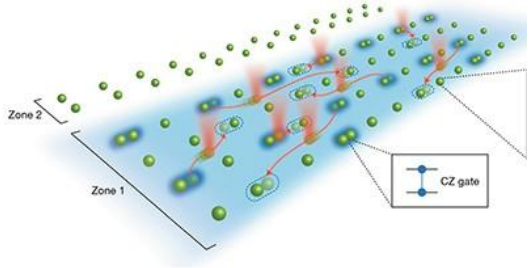
Ion Traps



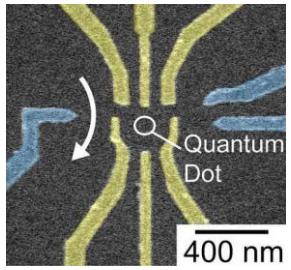
Photonics



Neutral Atoms



Quantum Dots



So… dream came true?

Is a 64-bit QPU better than your phone (64-bit CPU)?

In theory… it can be
2^{64} vs 64 better!

With it
I can hack credit cards!
(You better not)

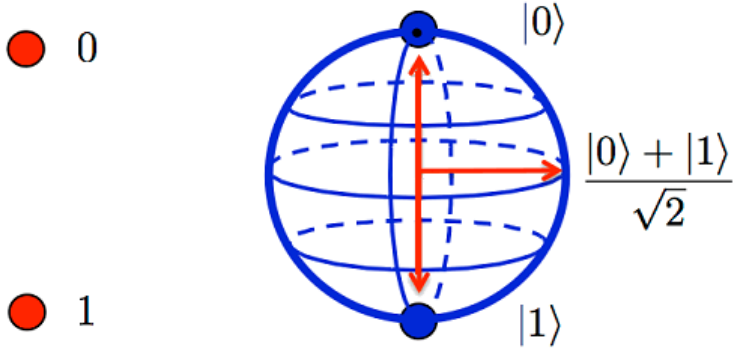
But…

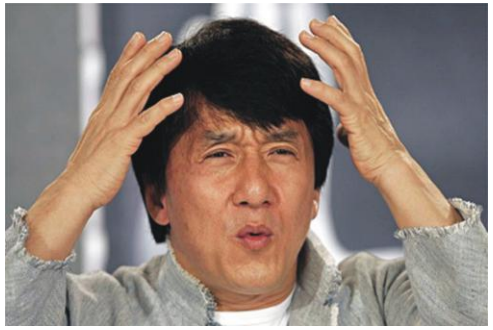
These are noisy (low quality) qubits
A lot of times when we compute they give us… well…

RUBBISH

But…

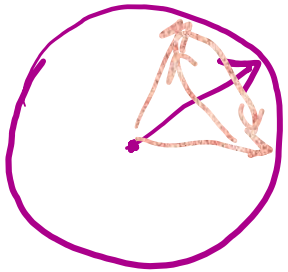
We know a way to make it work!

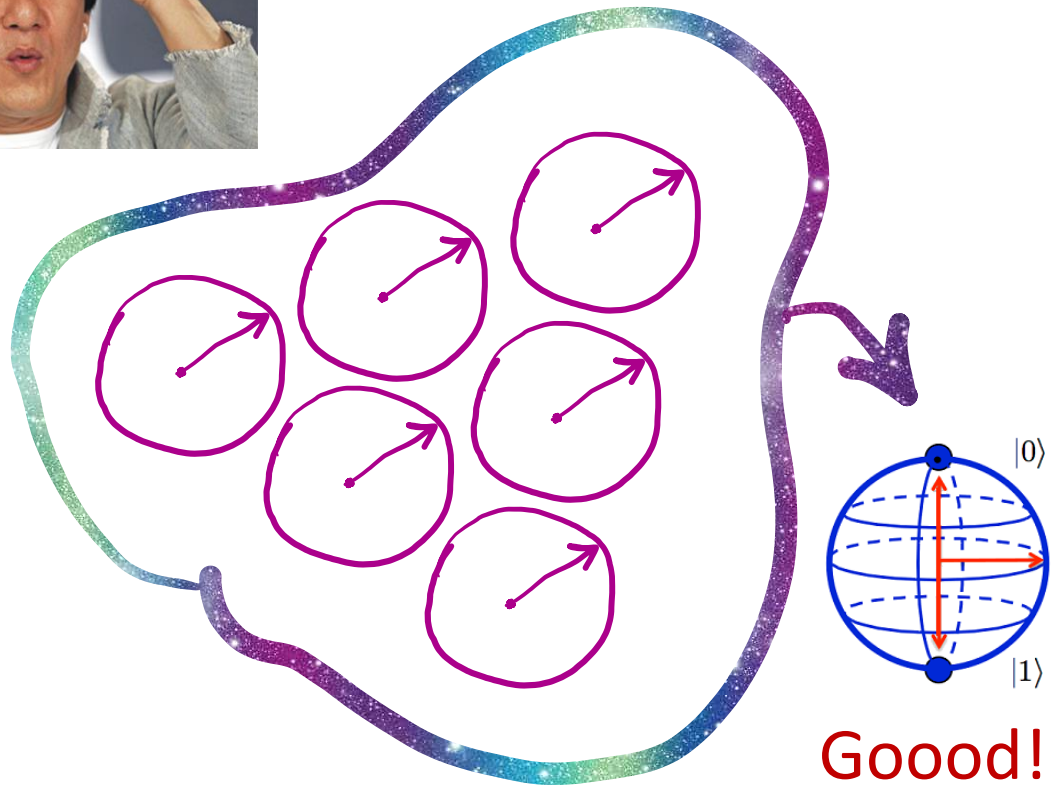




Bad

BAD!

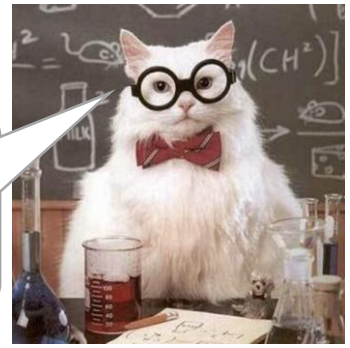




Goood!

So how many of these (bad ones) we need
to do something that we can't do with our laptops or
even our supercomputers?

~ 1,000,000

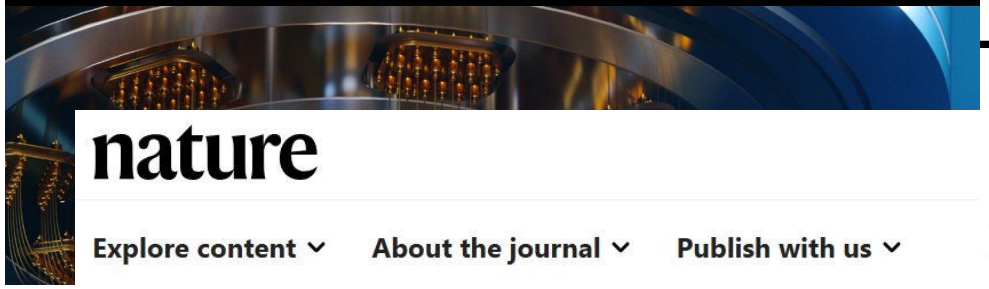


Don't take this number too seriously… matter of debate!

And this is called "Quantum Error Correction"

So dream came true or not?!

Quantum Computing Is Closer Than You Think



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Quantum error correction below the surface code threshold

Google Quantum AI and Collaborators

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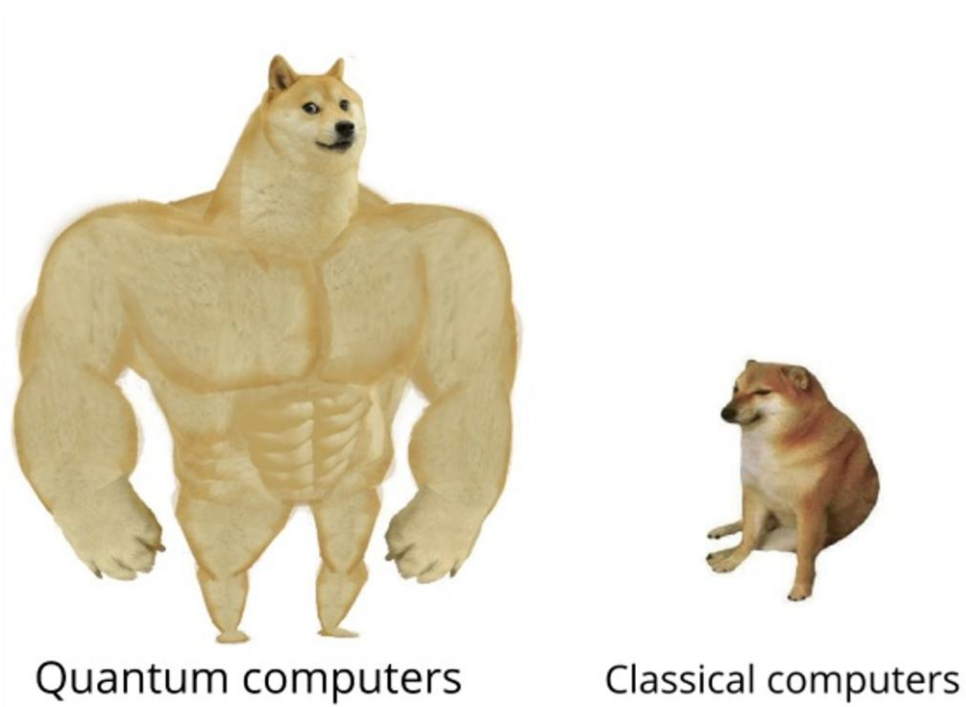
High-threshold and low-overhead fault-tolerant quantum memory

Sergey Bravyi, Andrew W. Cross, Jay M. Gambetta, Dmitri Maslov ✉, Patrick Rall & Theodore J. Yoder

Nature **627**, 778–782 (2024) | Cite this article

Quantum Computing Myth vs Reality #1

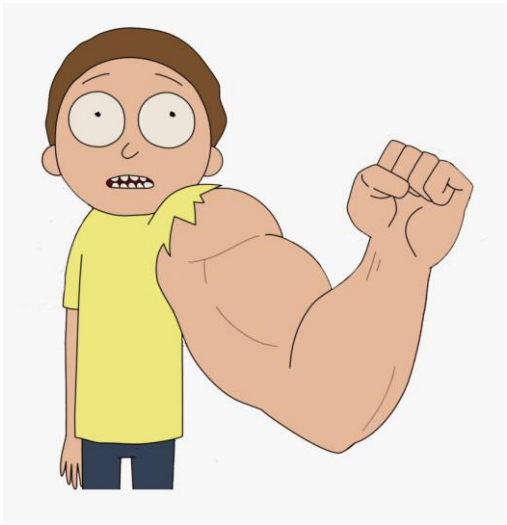
What people think



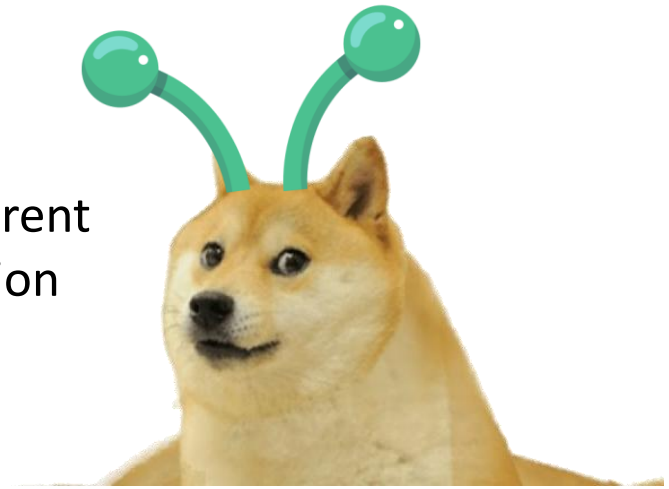
Super-powerful computers for everything!

Vs

It's a fundamentally different way of doing computation



What it really is



It can perform some tasks better than any classical computer (or that's what we believe)

Quantum Computing Myth vs Reality #2

Quantum Computers: What people think

Vs

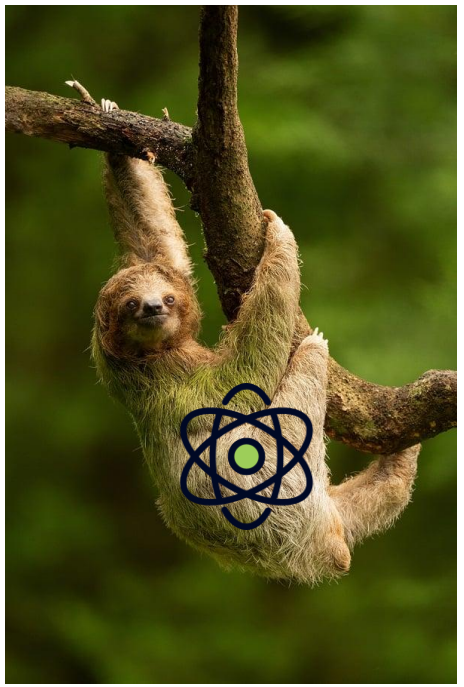
What it really is

Classical computers

Quantum computers

Myth: They're faster in performing operations

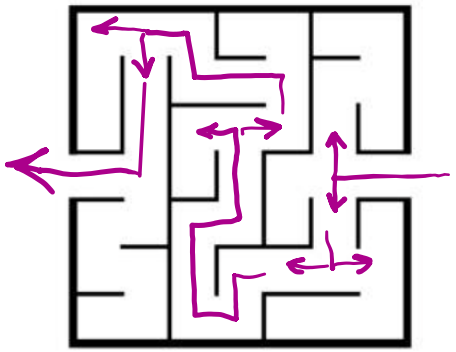
They're not faster! But they can do some tasks with less effort (less steps)

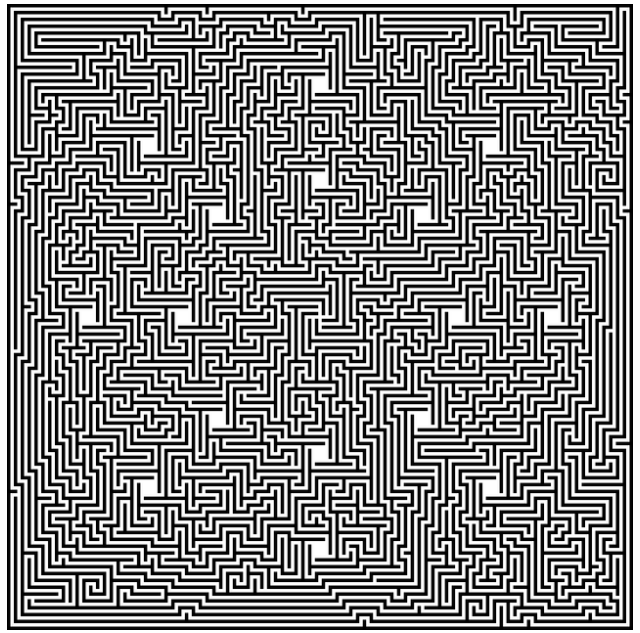


What do we mean by fewer steps?

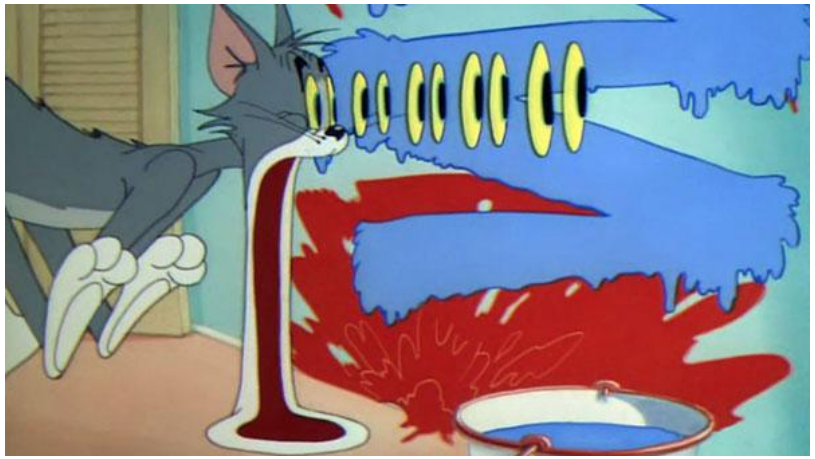
We believe there are mathematical problems that are "hard to solve"

Algorithms need more and more steps as we grow the problem size



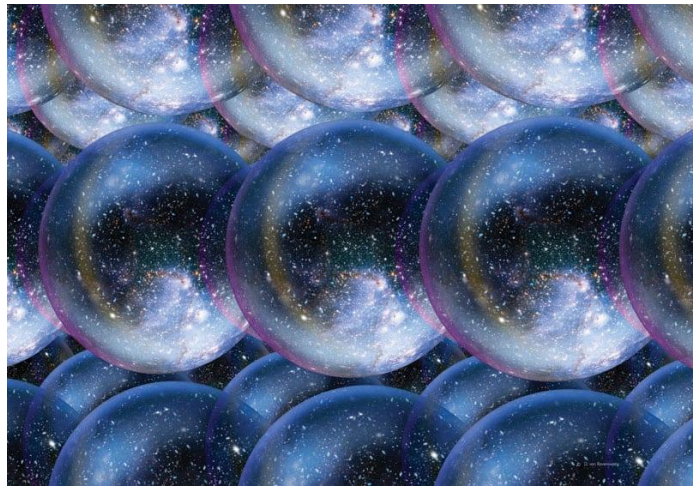


For some of these problems, we have a quantum algorithm that solves it efficiently (doesn't scale horribly when we make it larger)



Quantum Computing Myth vs Reality #3

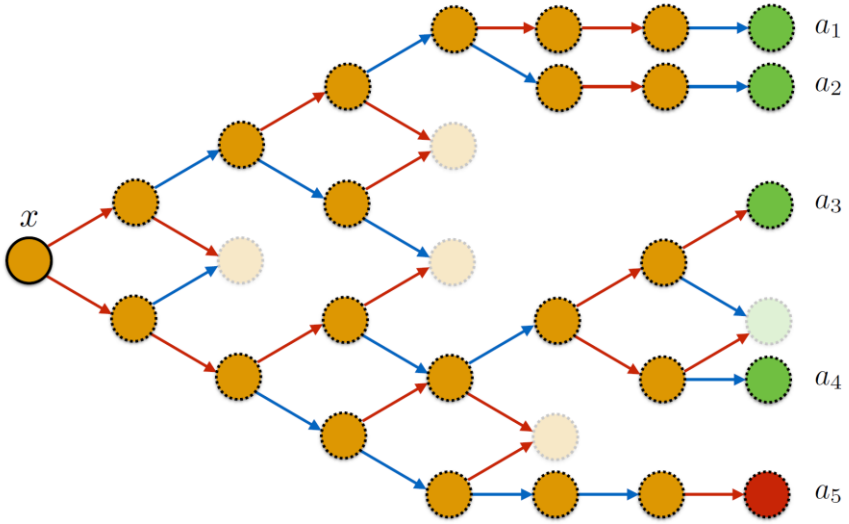
Quantum Computers: What people think



Quantum multiverse!

Vs

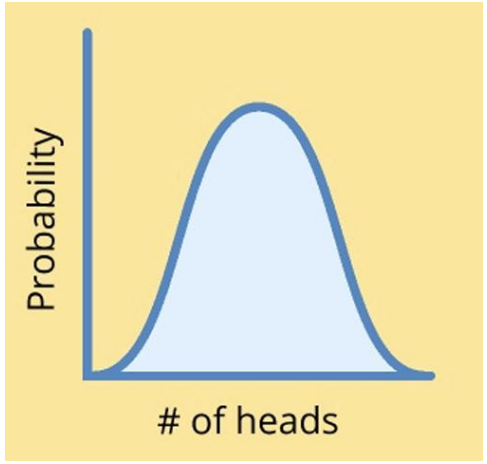
What it really is



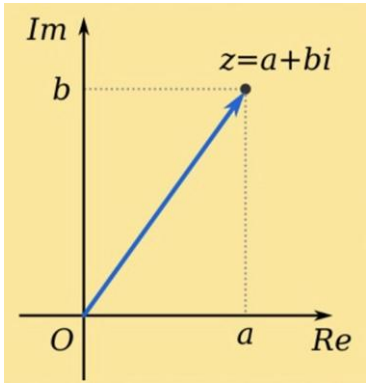
Myth: Quantum Computers Simultaneously perform all the branches of probabilistic computation and can use all the information!

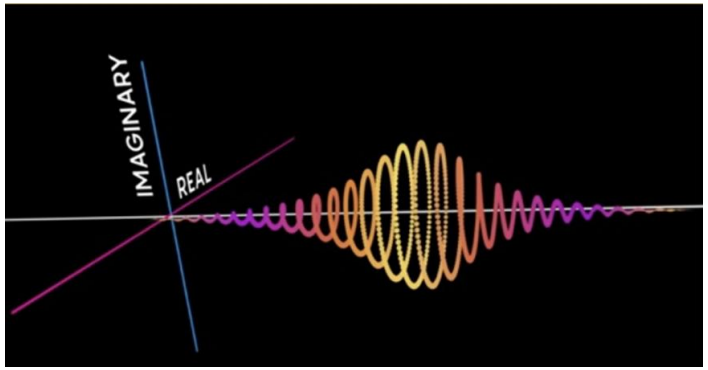
QC span the space of possibilities in a peculiar way (with complex probability-like things). But at the end of computation, we extract classical information through a single read-out/measurement, and we don't see those "unrealized" paths

Amplitude vs Probability



Probability is a real number between 0 and 1.

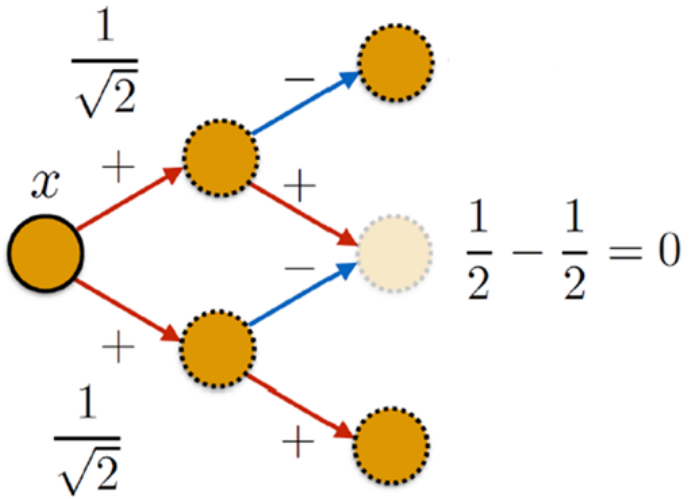




I behave like a wave too!

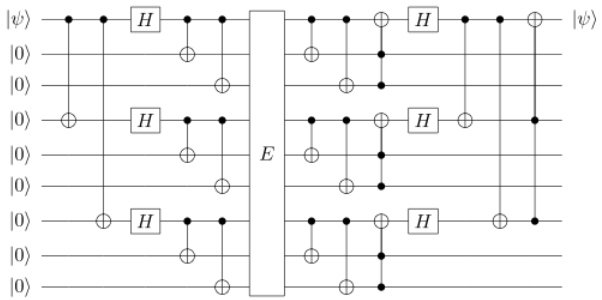
$\alpha|0\rangle + \beta|1\rangle$

Amplitude is like probability but with complex numbers!

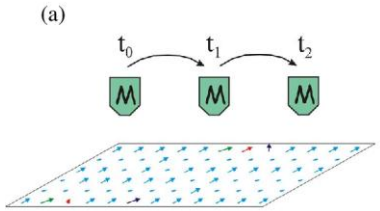


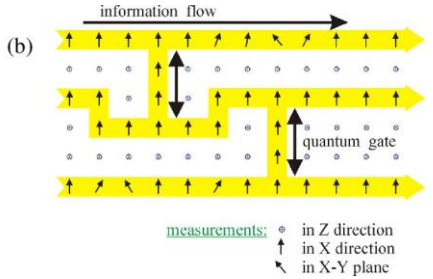
Different Models of Quantum Computing

Quantum Circuits



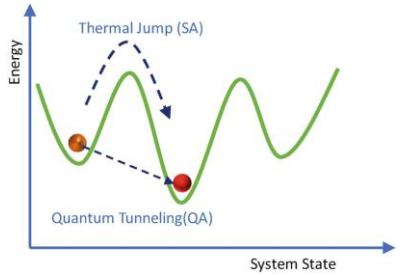
Measurement-based Quantum Computation



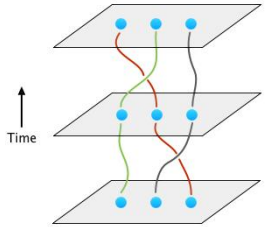


Adiabatic Quantum Computation

Quantum annealers

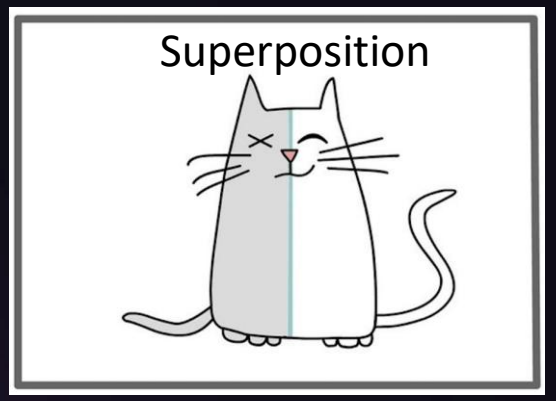


Topological Quantum Computation

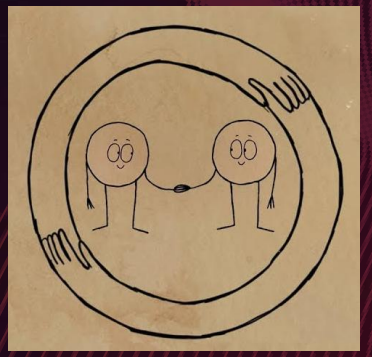


And you will hear a lot about these things:

Complex amplitudes:
new probability rules!



Probabilistic measurements and collapse



Entanglement

And after learning all that….
you shall never be the same ☺