CZECH AUSTRIAN PHOTONICS 2023 19.–20. 4.

(Photonic) quantum computer:
What is it and what can we do with it?

Who am I?

Iris Agresti

Post-doctoral researcher in the quantum informatio
and quantum computation group

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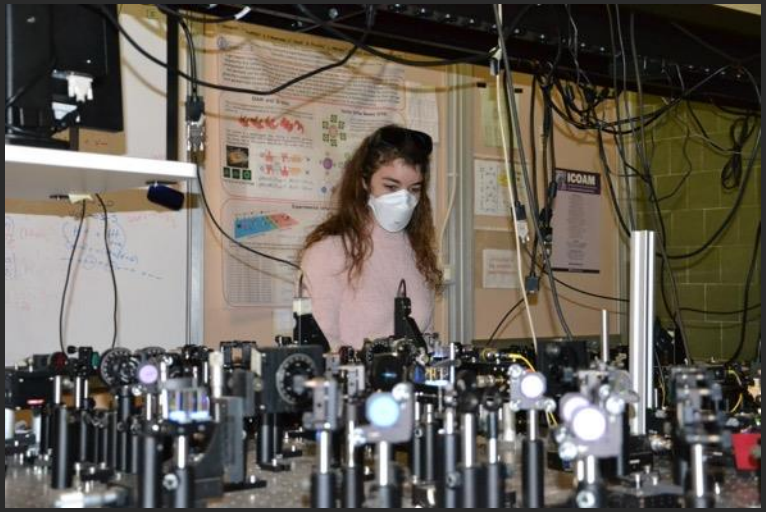
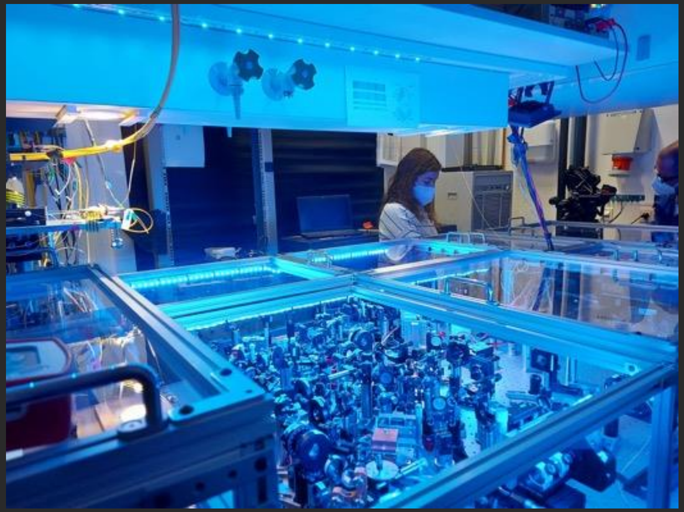
WE PLAY WITH LASERS!





When we say «computer», we usually think of…

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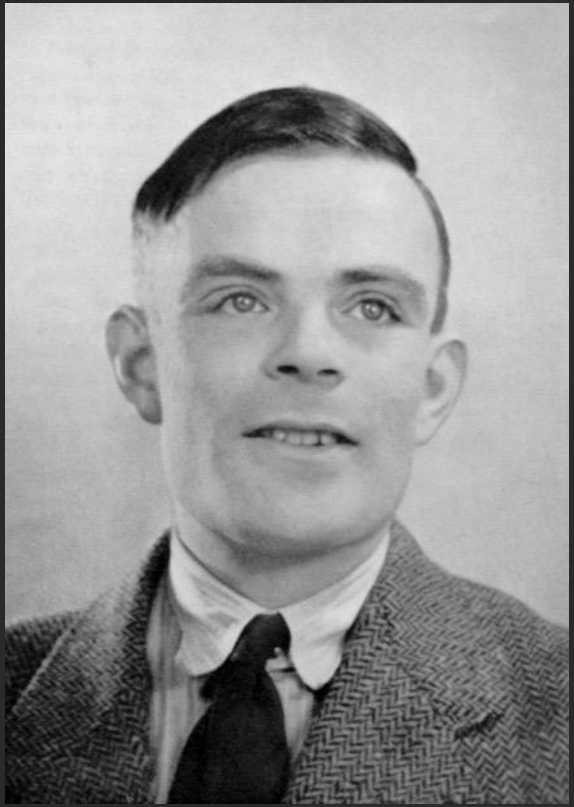
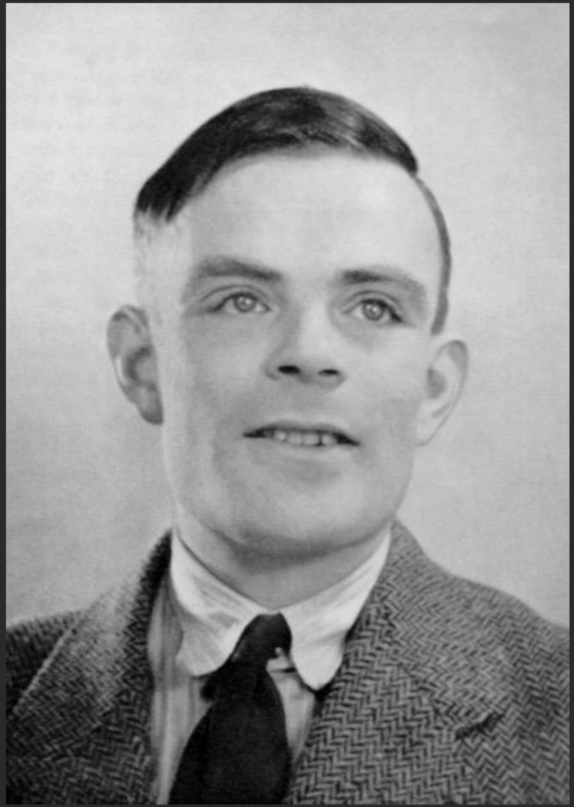
What is the formal definition?

Formal definition



Alan Turing (1912 – 1954)

Formal definition



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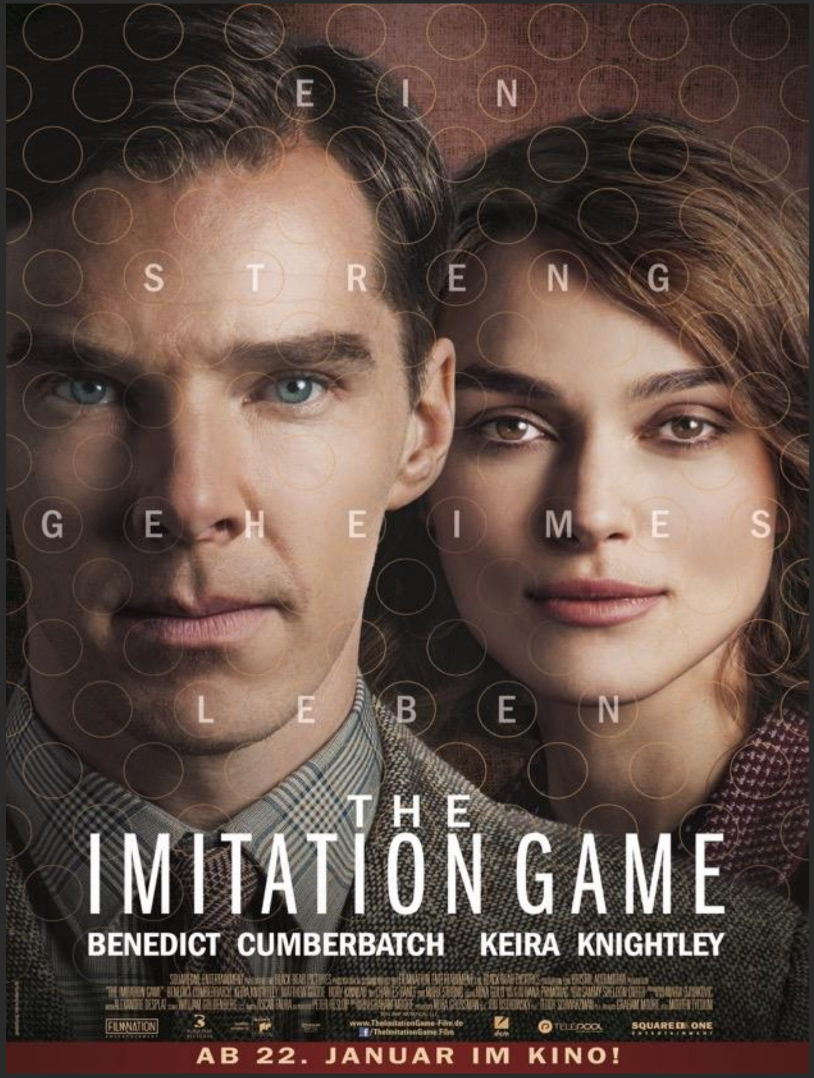
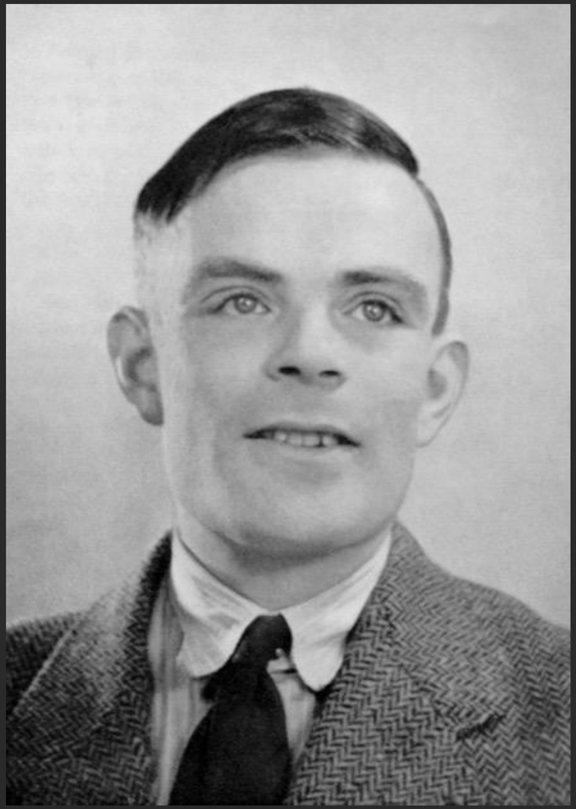


Formal definition



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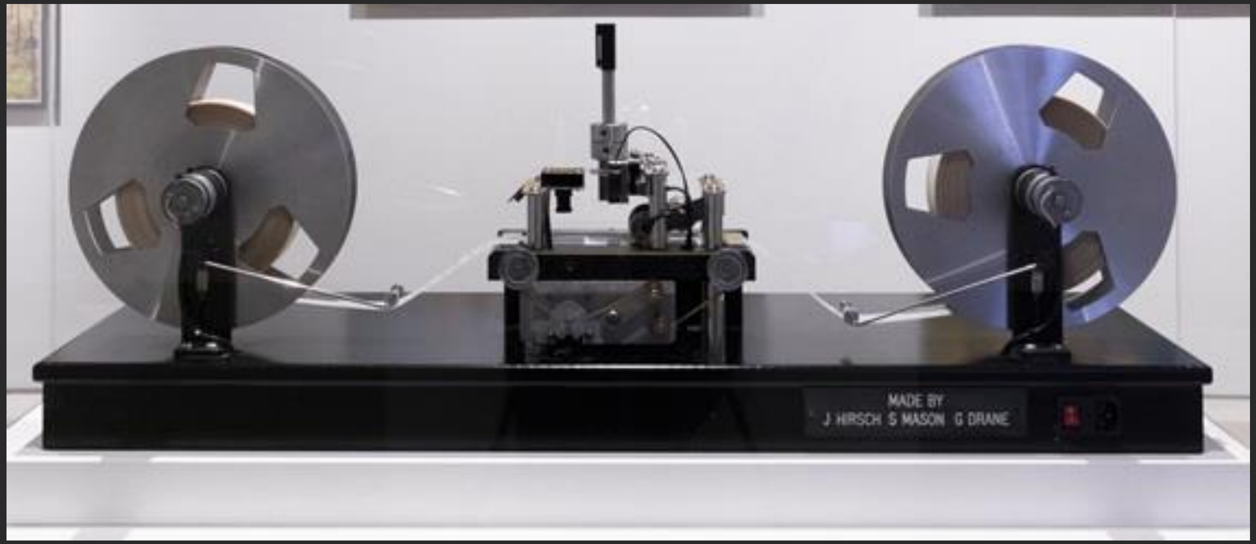
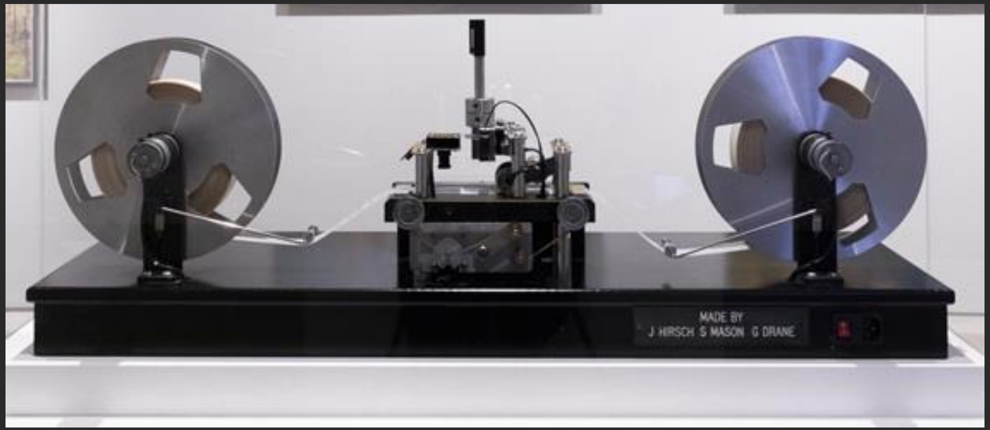
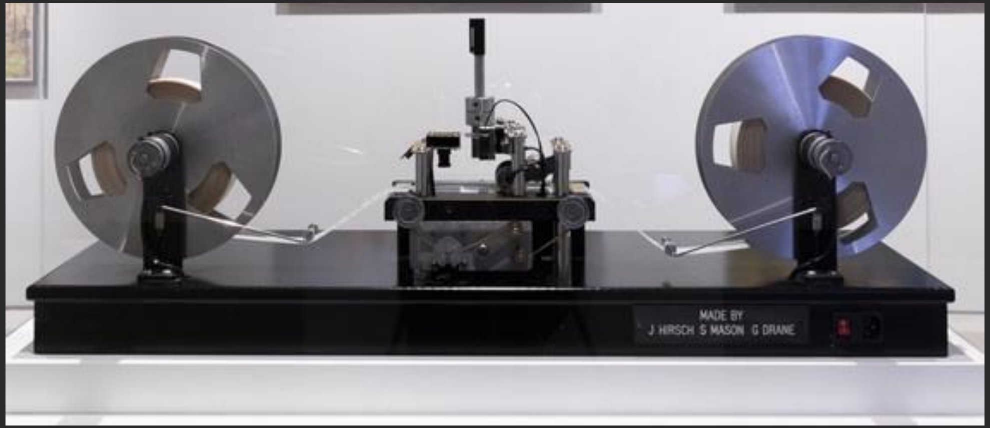


A Turing machine is a device that can perform a specific mathematical operation on an input, coming from an alphabet.

What's the difference?



What’s the difference?

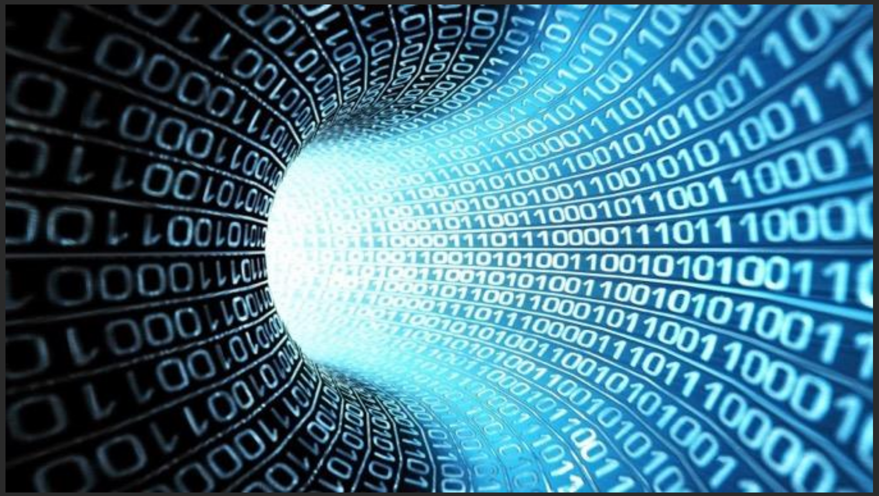


Our computers still make operations on inputs coming from an alphabet, but they can perform any operation we want:

they are Universal

The BIT

The alphabet that a computer uses is made of only two elements



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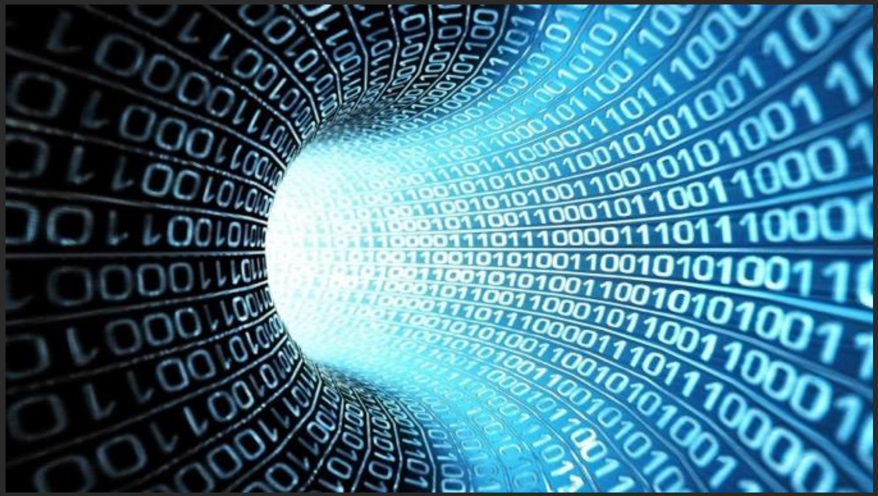
The BIT

The alphabet that a computer uses is made of only two elements



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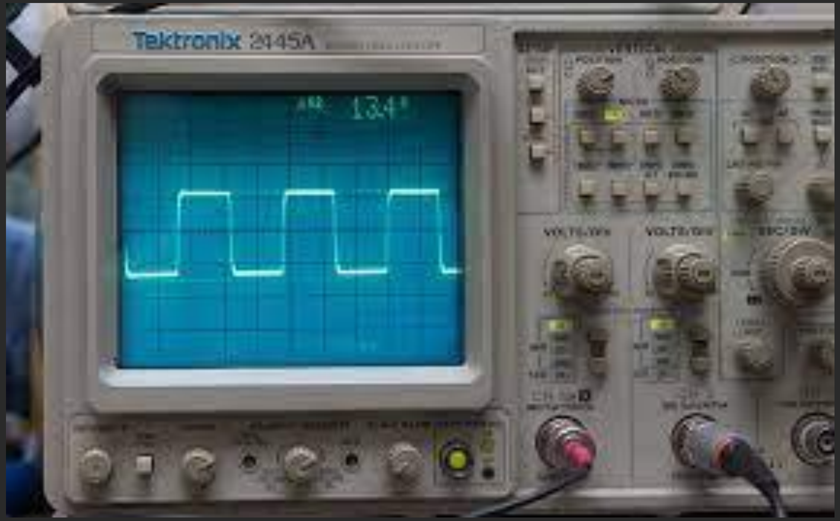


Difficult problems

A computer can do everything… but how hard is it for it?

2=2x1

3=3x1

4=2x2

.

.

.

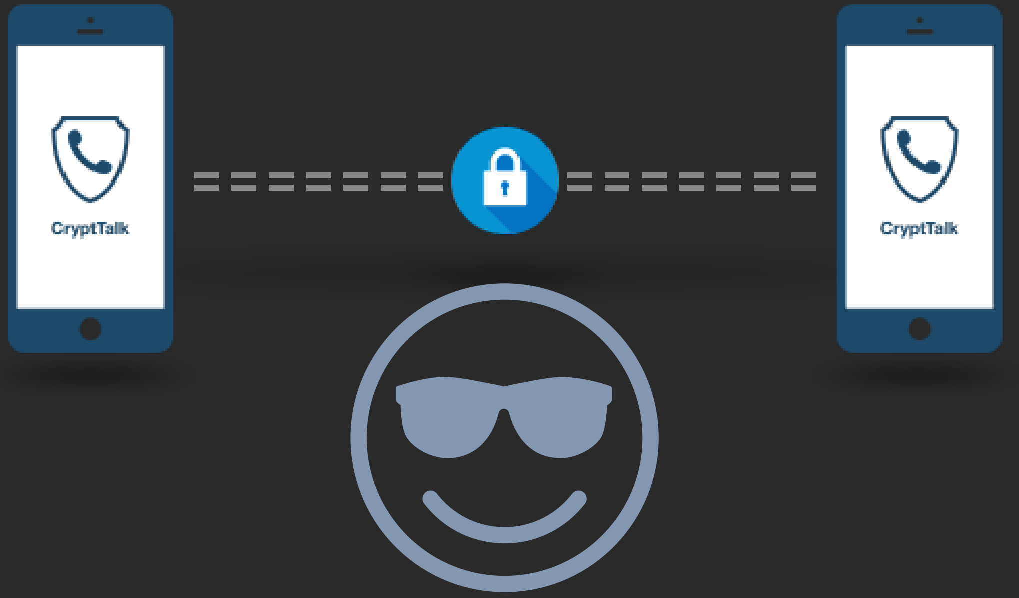
100=2x2x5x5

Some problems can be solved **efficiently**,

Others, like the factorization, require too much time/memory

Difficult problems

Many security and cryptography protocols rely on the fact that codes cannot be cracked in a short time by an adversary.



Quantum bit

We can use quantum states for our computation.

0 1 $|0\rangle + |1\rangle$

Using quantum bits enables more efficient computation.

~~Difficult problems~~

2=2x1

3=3x1

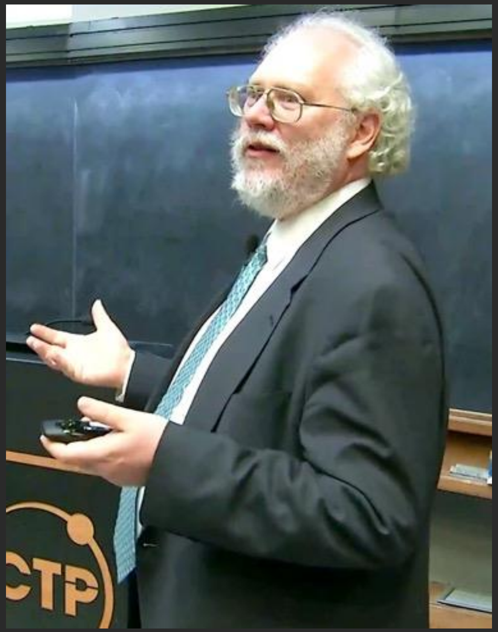
4=2x2

.

.

.

100=2x2x5x5

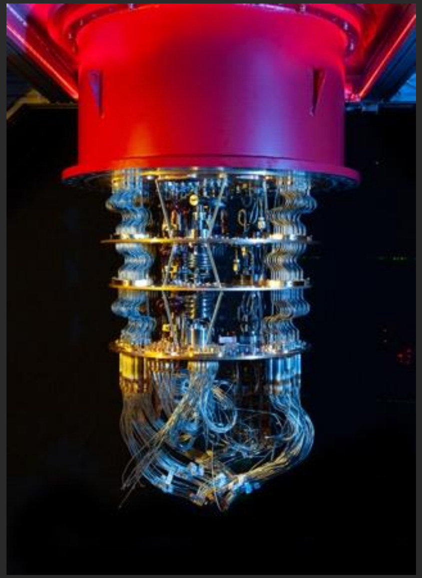


Peter Shor(1954)

A quantum computer can factorize large numbers efficiently!

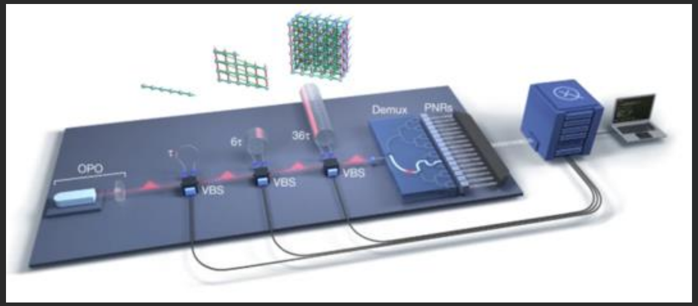
Latest news

Three experiments have been performed experimentally showing that quantum computers are more powerful than classical ones



Google AI Quantum, Mountain View, CA, USA (2019)

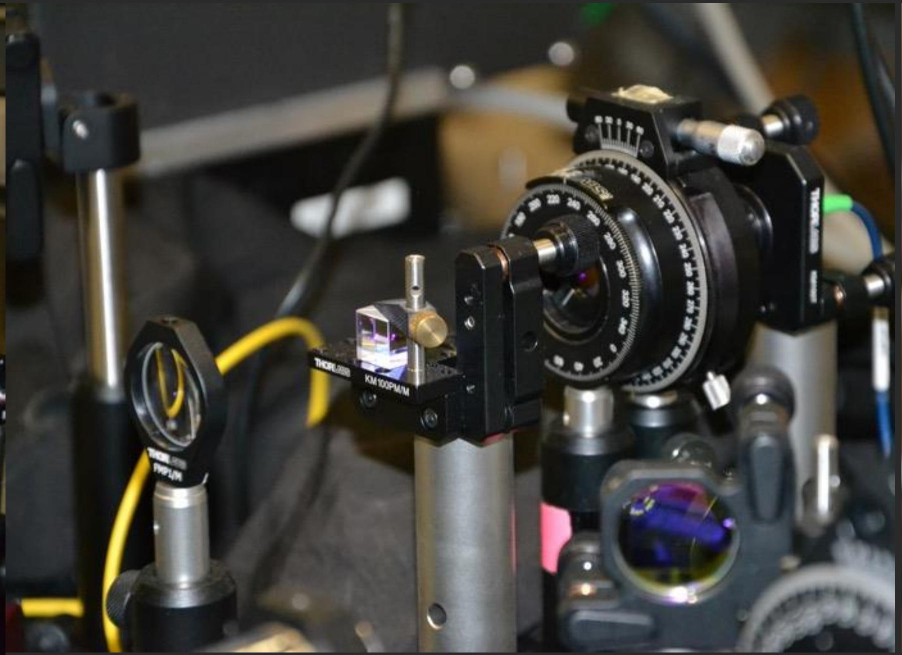
University of science and technology of China, Hefei, Anhui (2020)

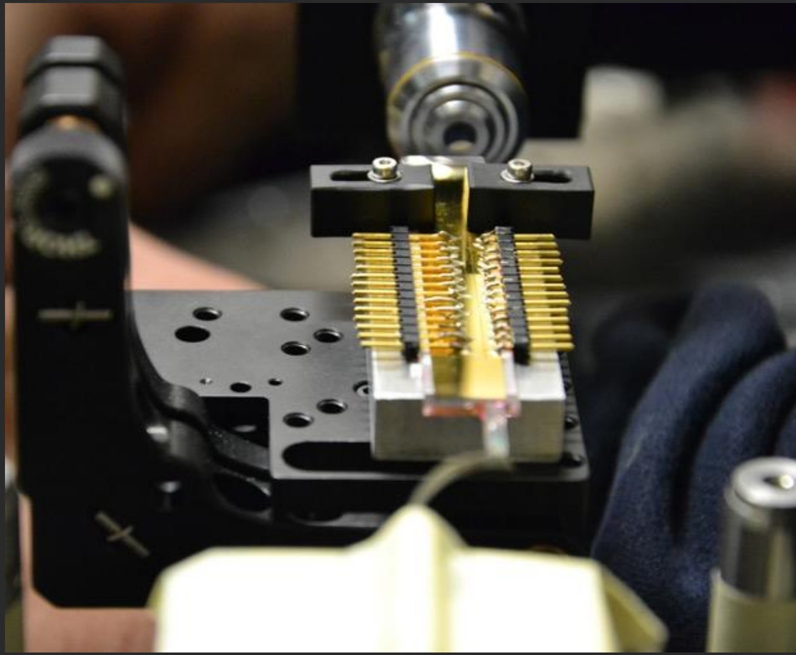


Xanadu, Toronto, ON, Canada (2022)

How can we realize and manipulate qubits?

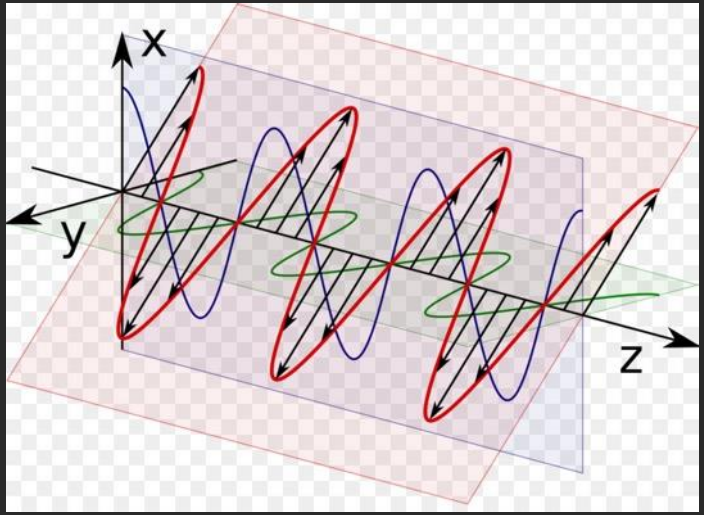
We can create quantum states through photons





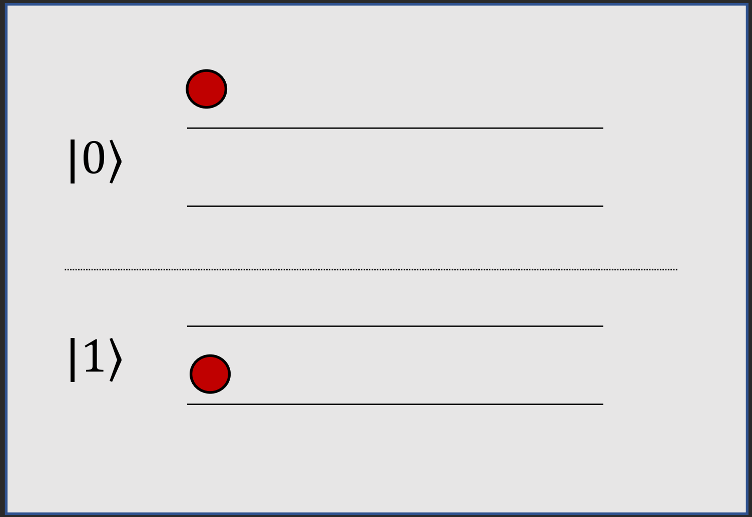
Possible information encodings

Polarization



$|0\rangle$ and $|1\rangle$ are orthogonal polarization states

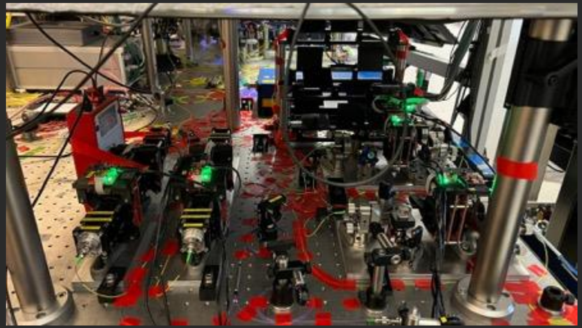
Path

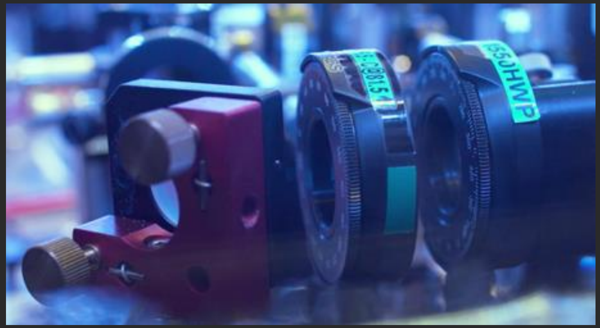


$|0\rangle$ and $|1\rangle$ are different paths taken by photons

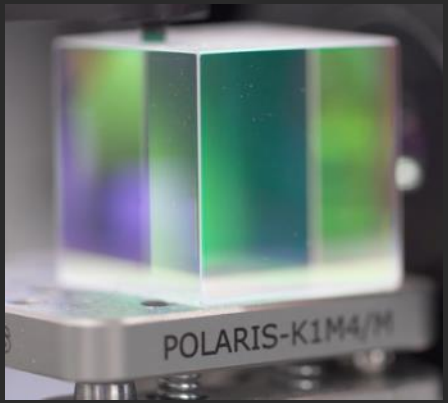
Why photons?

- They are easy to manipulate (high fidelity gates)



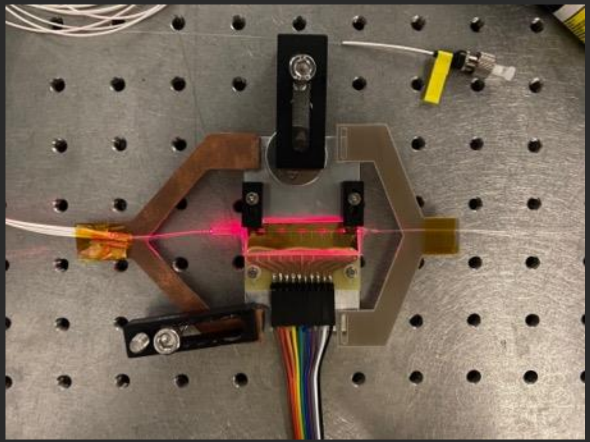


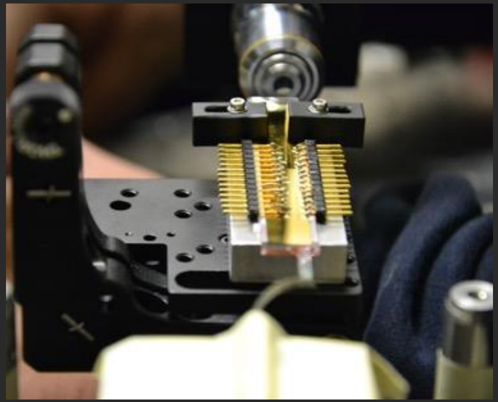
Polarization rotators

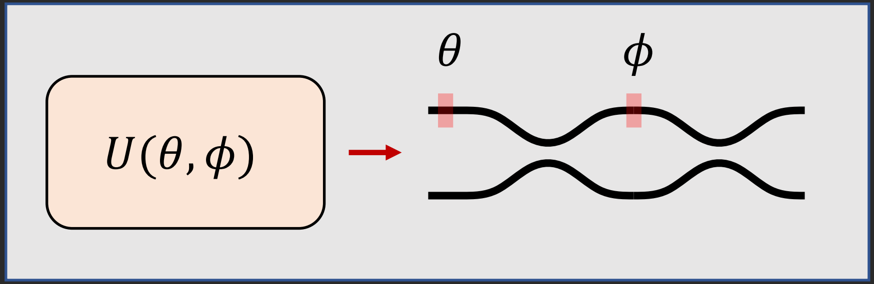


Projective measurement

Tunable circuits



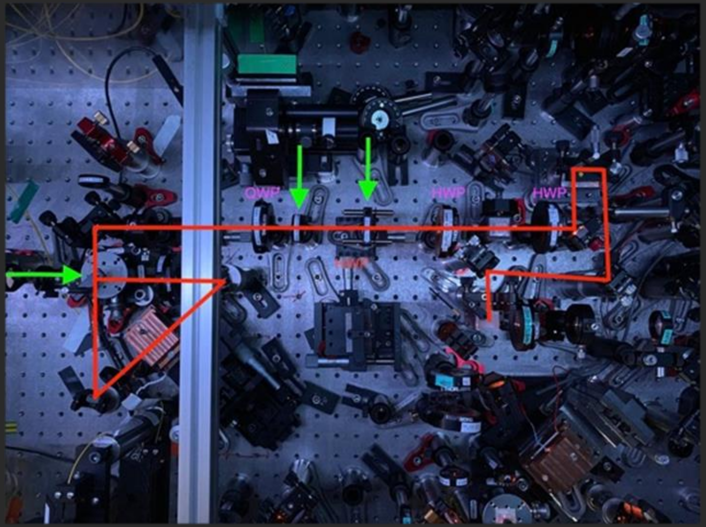




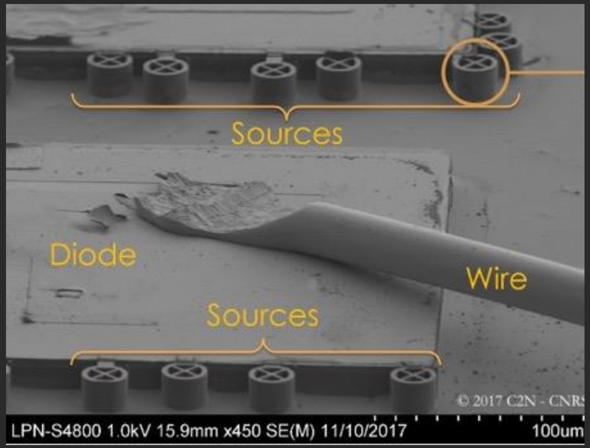
Measurement building block

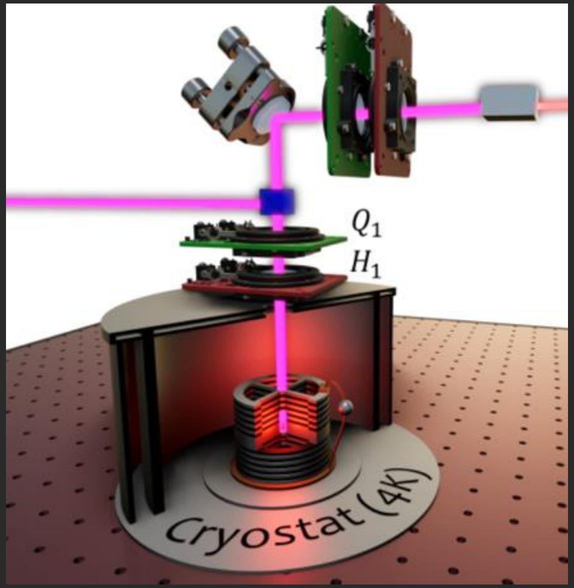
Why photons?

- Easy to generate



Spontaneous Parametric Down-Conversion

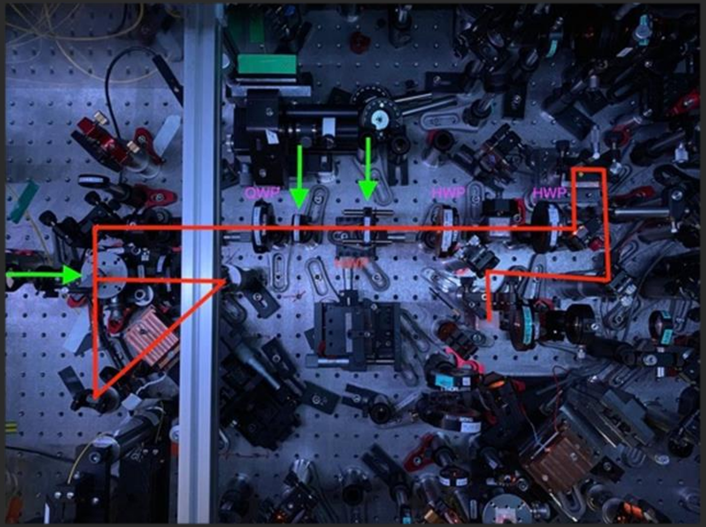


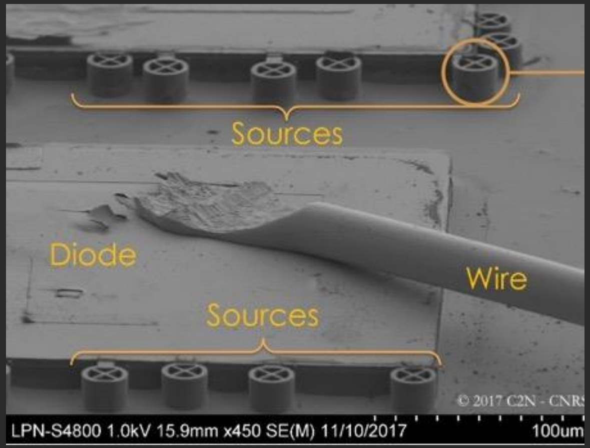


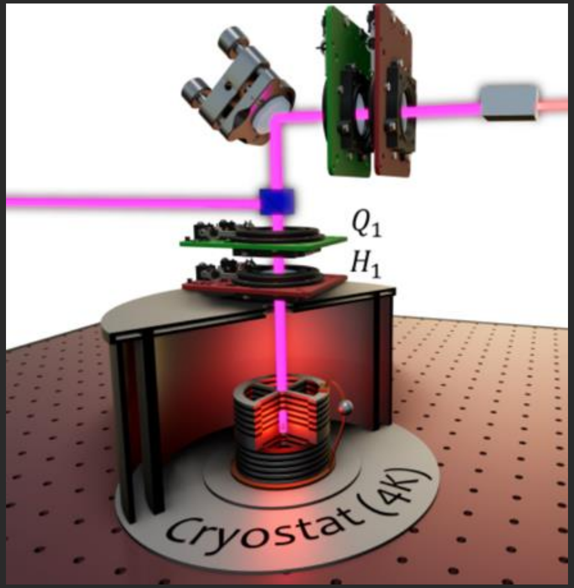
Quantum dots

Why photons?

- Easy to generate







<u>Spontaneous Parametric Down-Conversion</u>

- Easy to realize
- Entangled states
- Versatile

- Not on demand (low rates)

<u>Quantum dots</u>

- On demand (high rates)

- Hard to generate entangled states
- Difficult to use

Why photons?

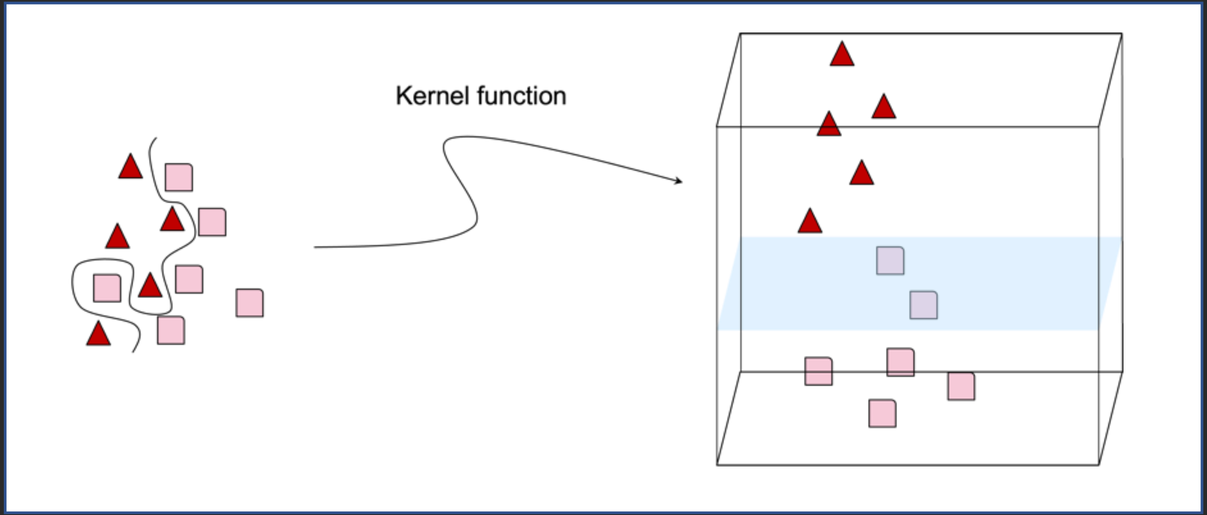
- Fast and no interaction with environment

Low decoherence

Hard to implement two-qubit gates

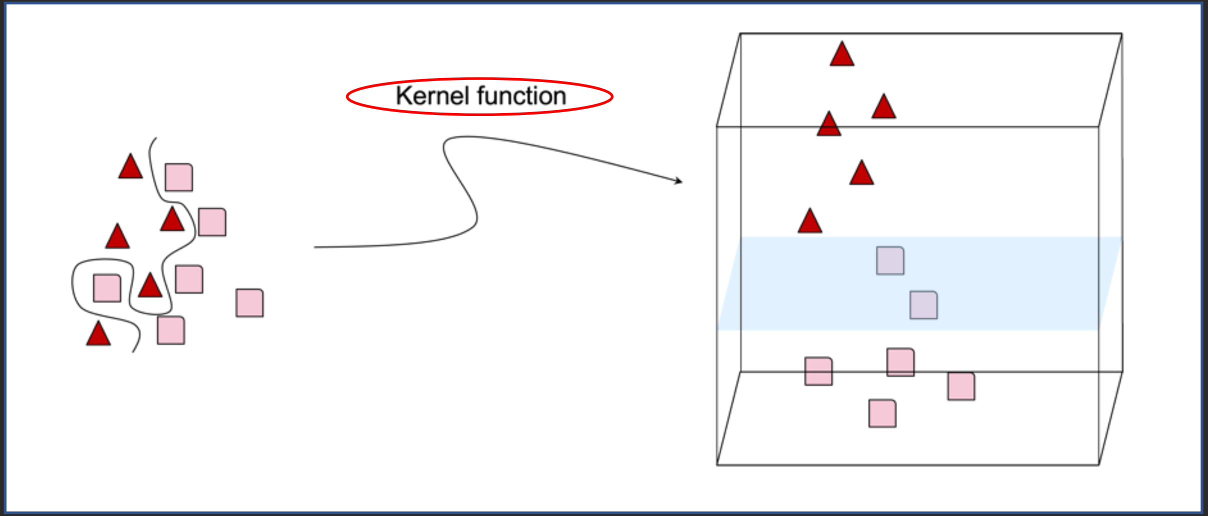
Research lines in Vienna

Kernel estimation

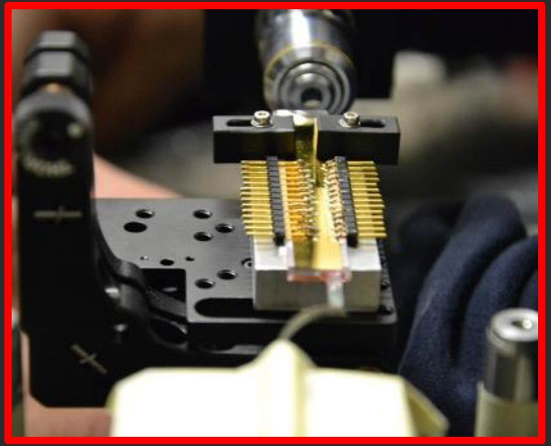


Research lines in Vienna

Kernel estimation

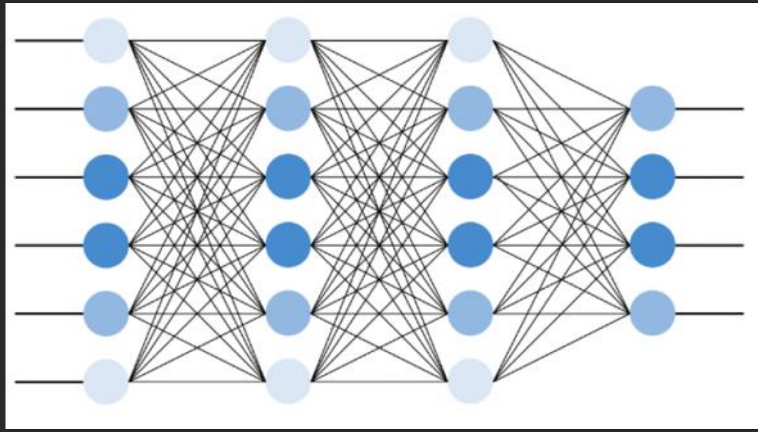


Implementing tbe kernel function on a photonic circuit can give higher accuracies than the classical case.



Research lines in Vienna

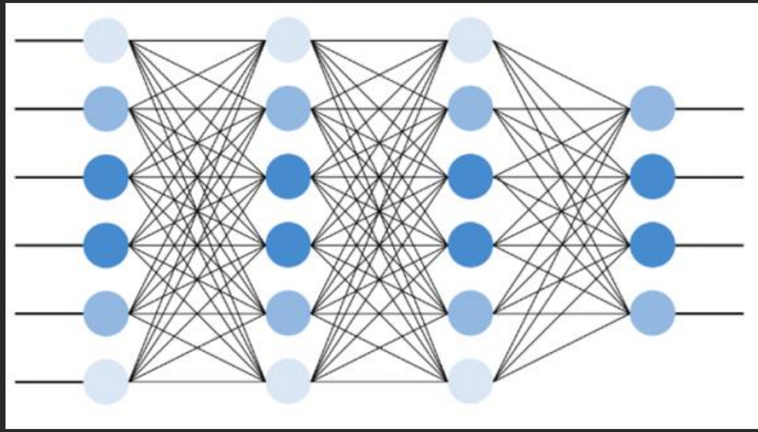
Machine learning models require non-linearities for the learning process

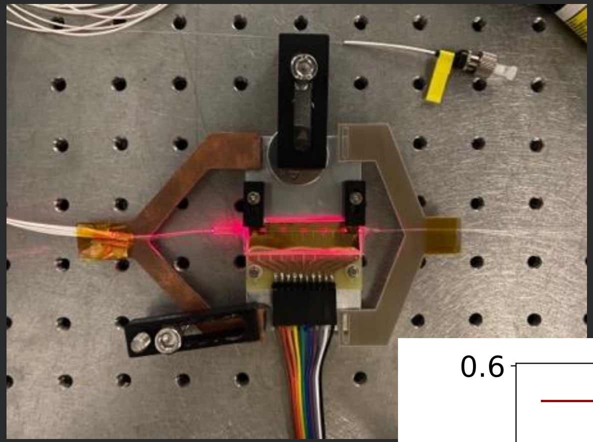


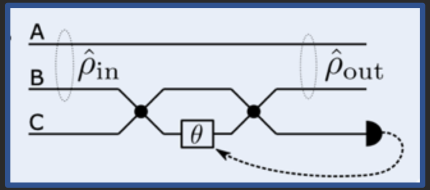
Research lines in Vienna

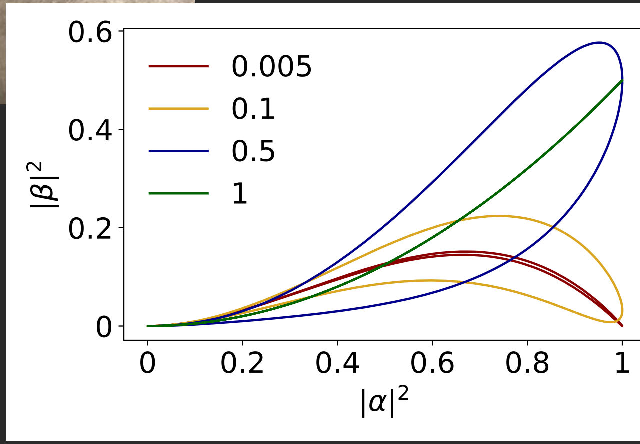
Memristor chip

Machine learning models require non-linearities for the learning process





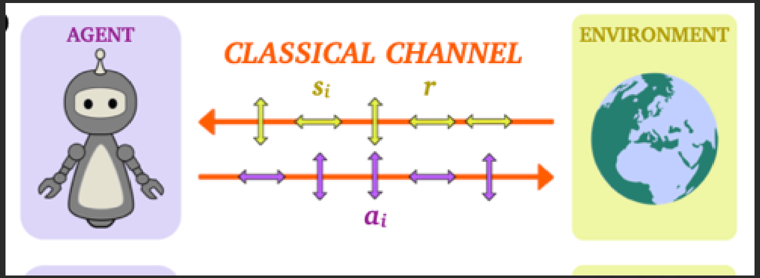




The operation of the chip conditioned on one output we get a nonlinear behaviour

Research lines in Vienna

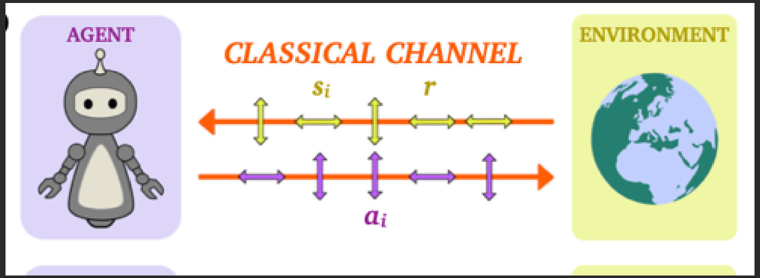
Reinforcement learning



An agent learns through the interaction with the environment

Research lines in Vienna

Reinforcement learning



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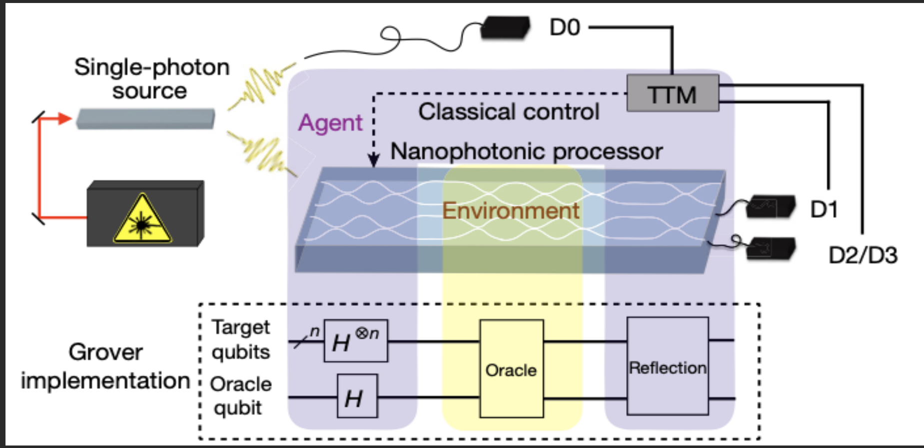
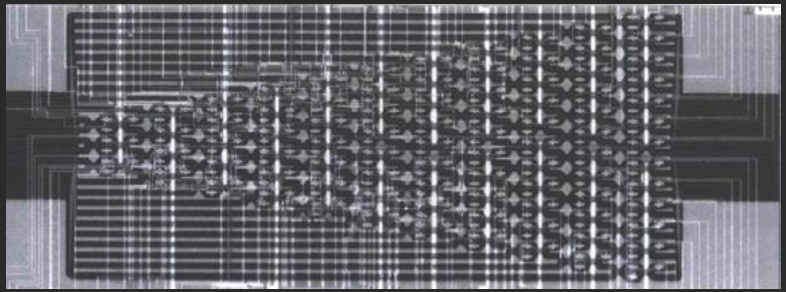


4.9 mm



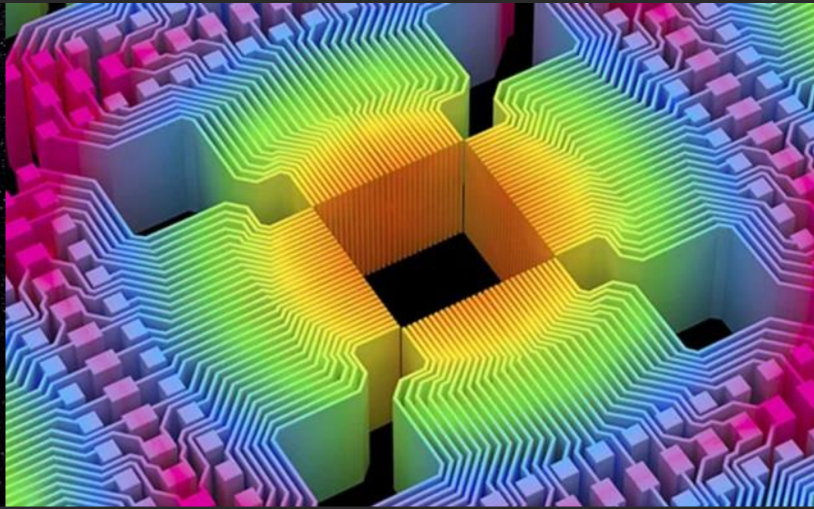
2.4 mm

A quantum strategy guarantees a speed-up in the learning

Future developments

Quantum Internet

Secure communication



Universal quantum computer