CSC

ICT Solutions for Brilliant Minds

Webinar: What is Quantum Computing?

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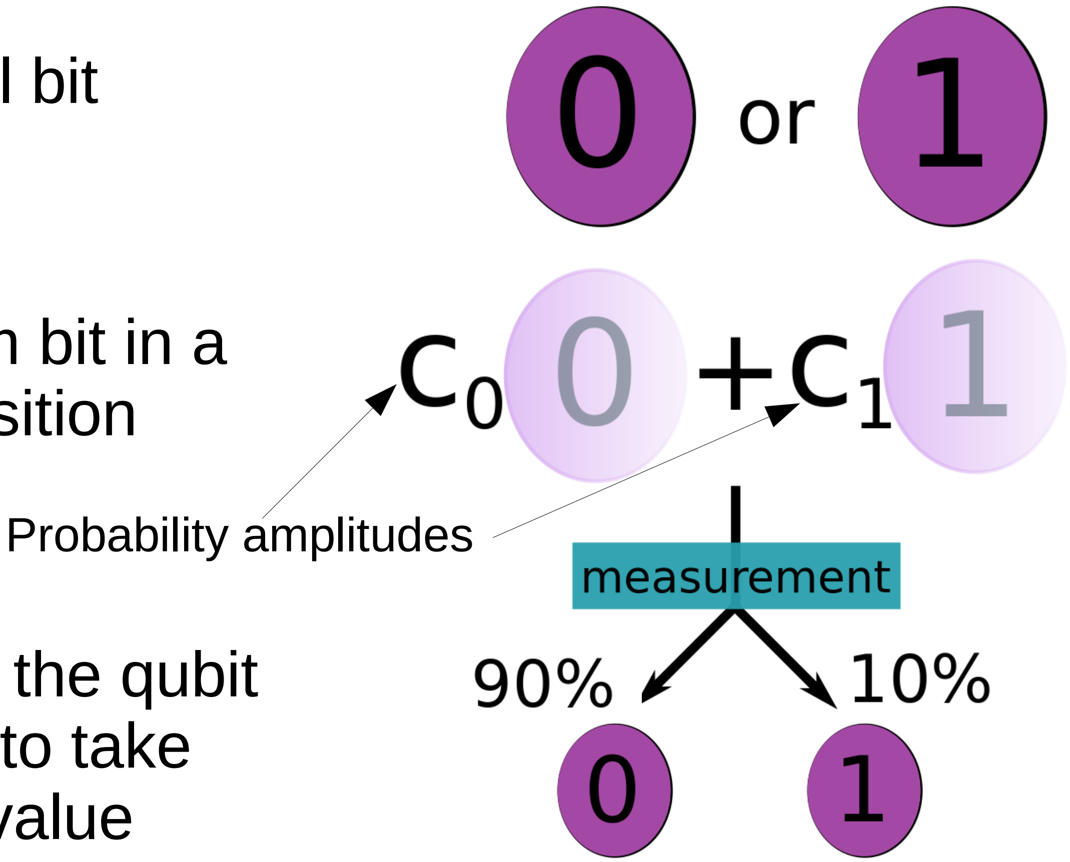
Going quantum

- Ordinary computing:
  - Realized as logical operations on strings of bits (0’s and 1’s)
  - Bits are represented as a low (0) or high (1) current value of a transistor

- Quantum computing:
  - Bits are mapped to a quantum system with two possible values e.g. electron on ground (0) or excited state (1)
  - Classical logic is replaced by the rules of quantum mechanics

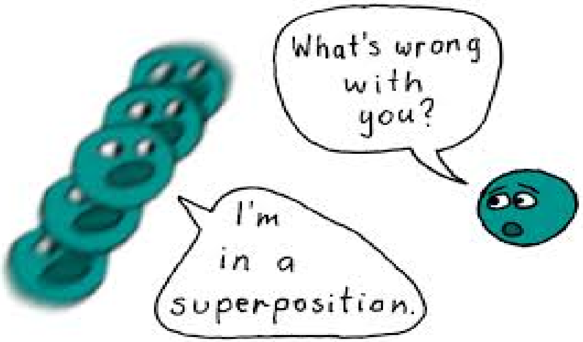
From bits to qubits

- Classical bit
- Quantum bit in a superposition
- Reading the qubit forces it to take definite value



Quantum gains

- Storing information in qubits yields three new resources that can be harnessed in computing
  - Superposition → yields parallelism
  - Interference → amplifies chance of correct output by allowing manipulation of probabilities
  - Entanglement → enables efficient control of multiple qubits



Credit: CC BY-SA 3.0

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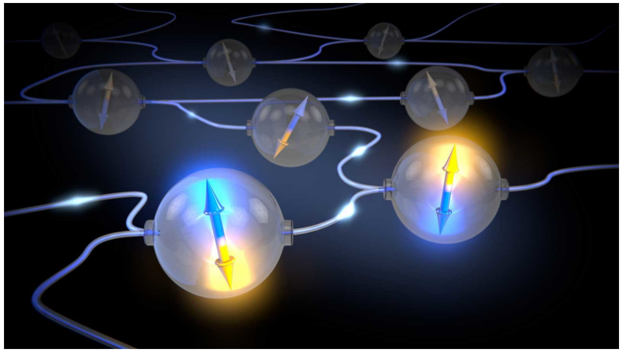
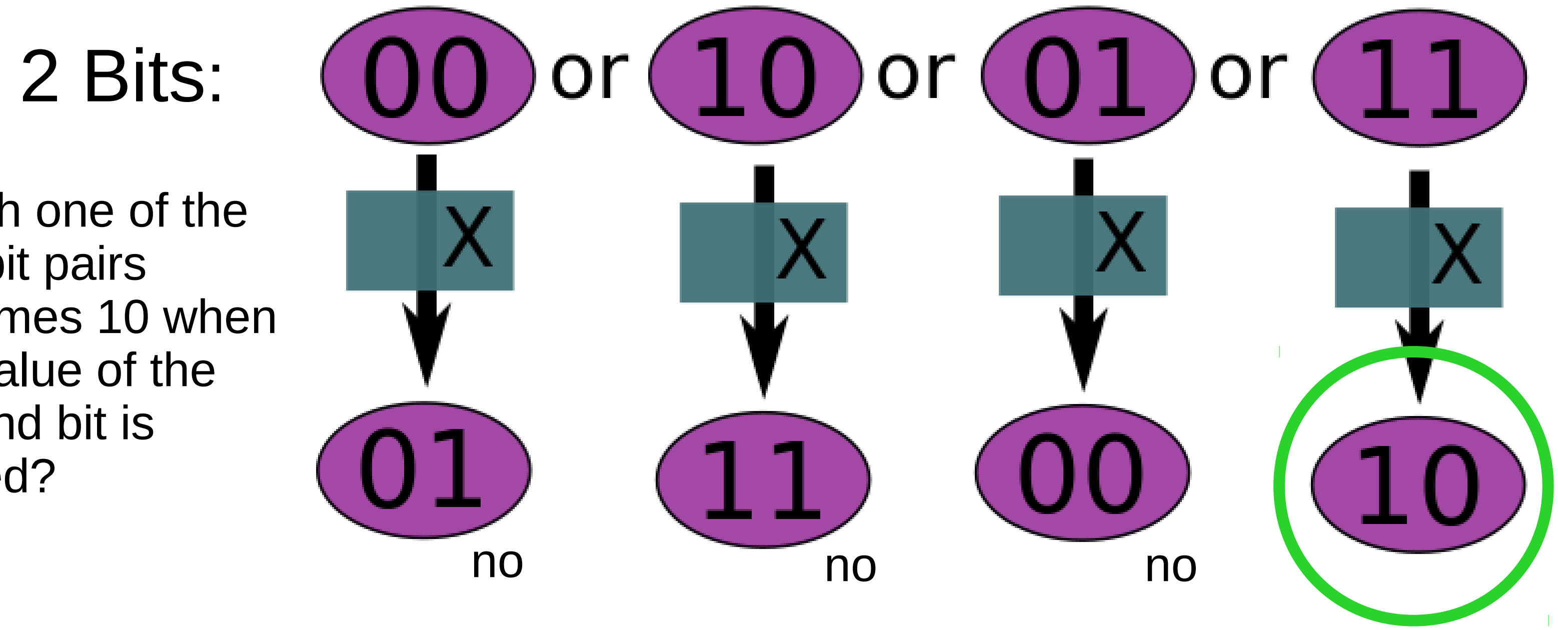


Credit: Delft University of Technology

Quantum parallelism

- Consider first a pair of ordinary bits

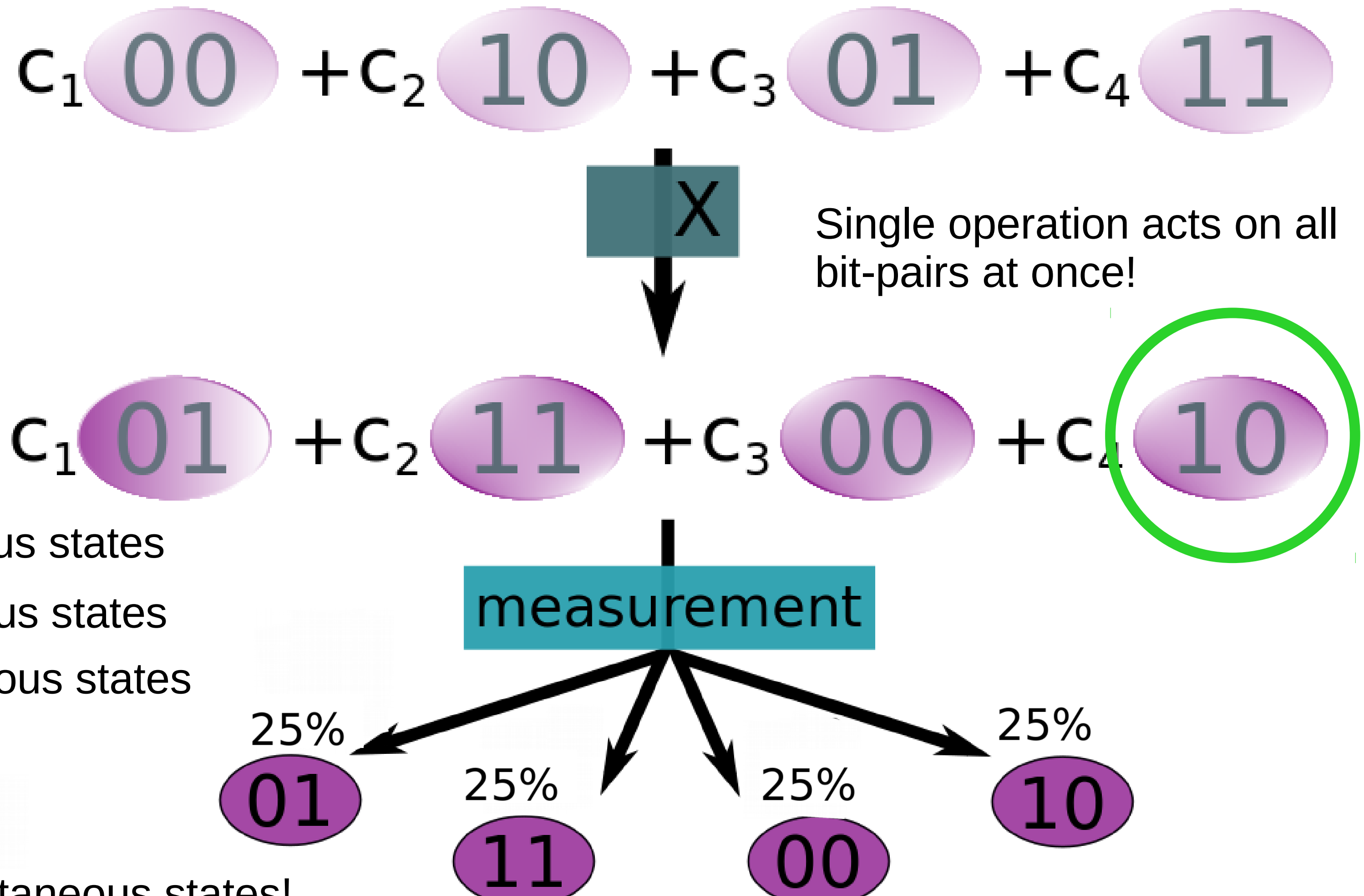


Which one of the two-bit pairs becomes 10 when the value of the second bit is flipped?

Quantum parallelism

- Consider then a pair of qubits in a superposition state

2 Qubits:



Which one of the two-bit pairs becomes 10 when the second bit is flipped?

2 qubits: 4 simultaneous states

3 qubits: 8 simultaneous states

4 qubits: 16 simultaneous states

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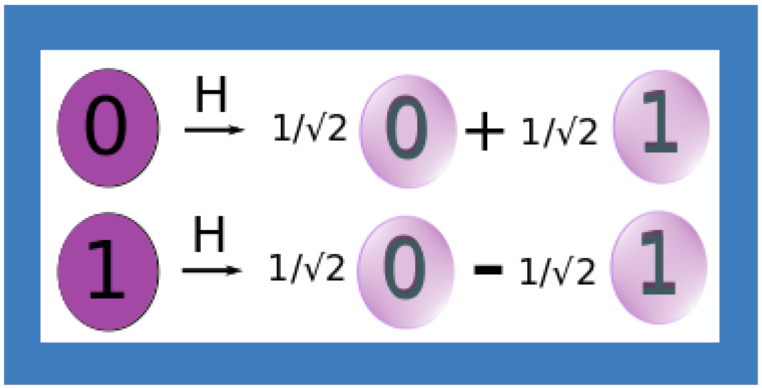
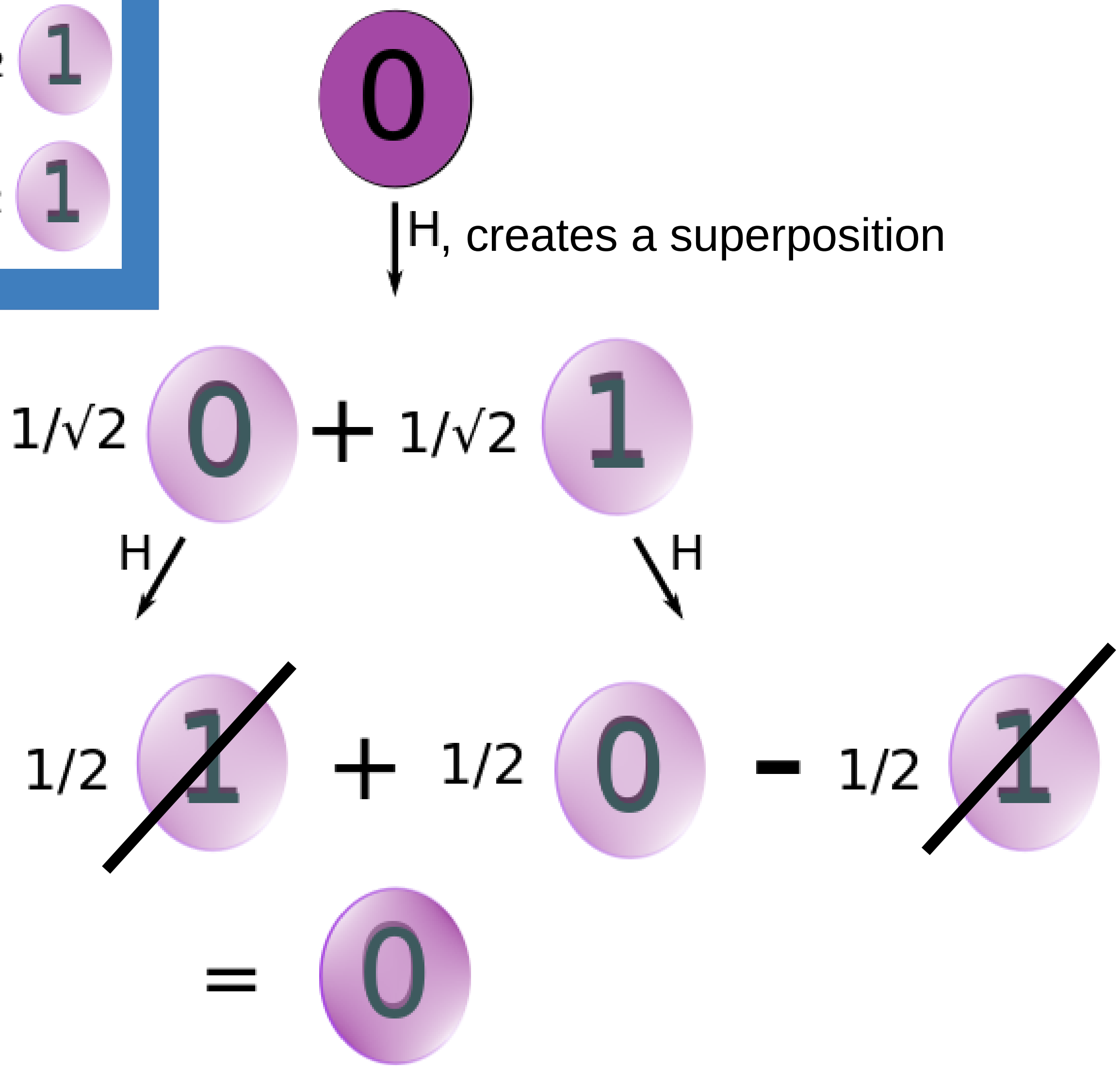
300 qubits: 10^{90} simultaneous states!

Interference

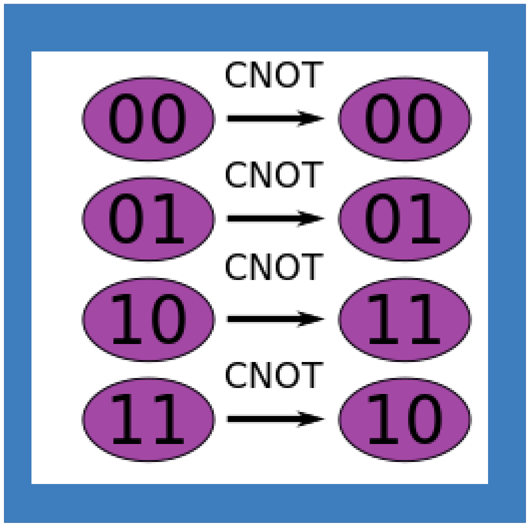
Hadamard gate

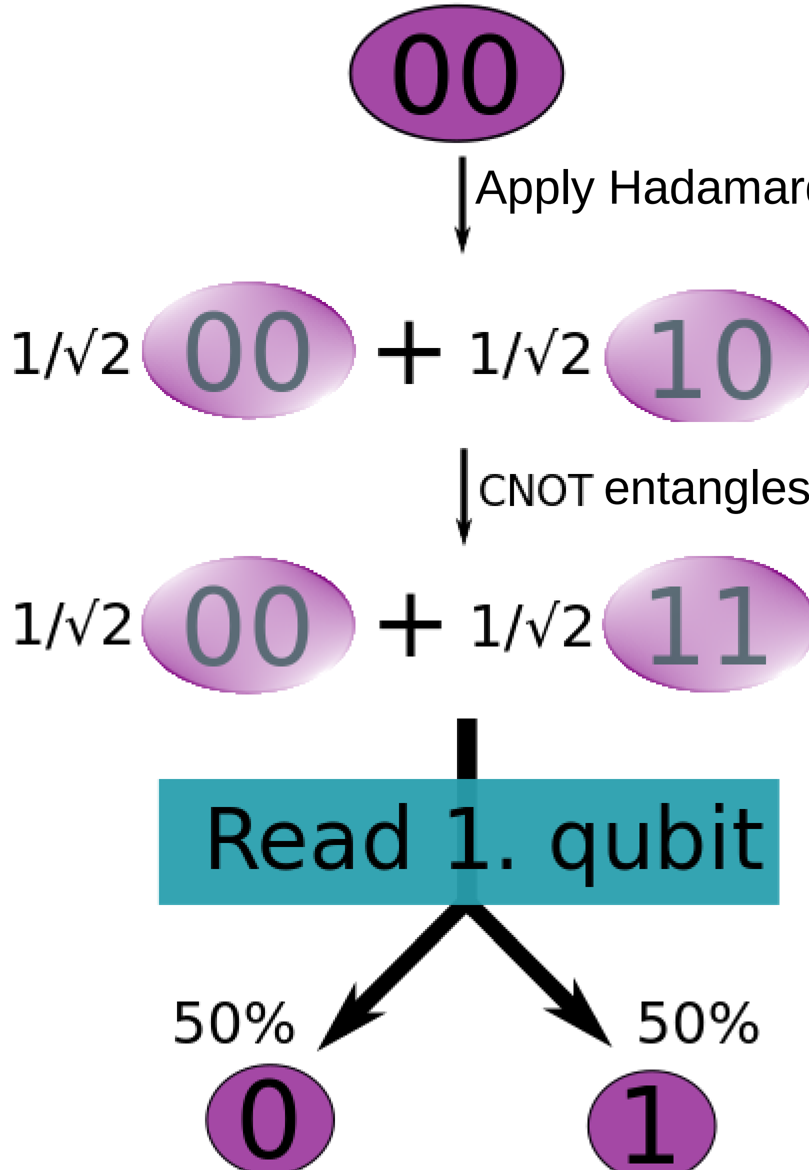




Entanglement

Controlled-NOT gate





Second qubit?

Always same as the first qubit!

Quantum supremacy

- Problems that are too time consuming for classical computers can be solved by quantum algorithms
  - Search of huge databases
  - Factoring large numbers (cryptography)
  - Complicated optimization problems
  - Simulation of complicated systems

Quantum drawbacks

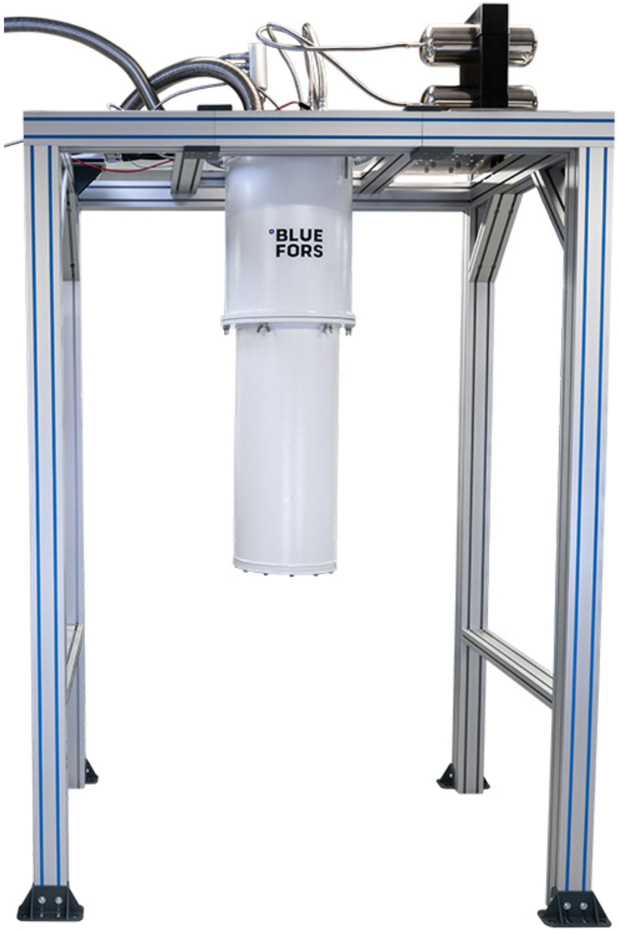
- The qubits are extremely sensitive to outside disturbances: air molecules, thermal energy, vibrations and electromagnetic fields can alter their value

  → quantum processors must be kept in a vacuum near absolute zero degrees and be protected from electromagnetic fields

- Even completely shielded qubits can suffer erroneous bit-flips due to intrinsic quantum fluctuations

- Furthermore, the outside disturbances will completely destroy the superposition within millisecond

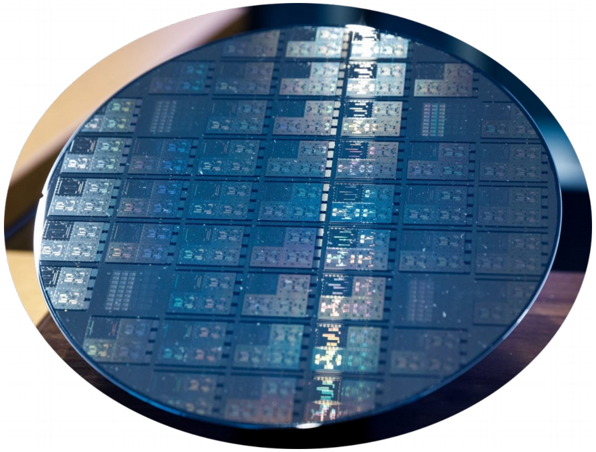
  → any calculations have to be performed before that



Credit: Bluefors

Dealing with errors

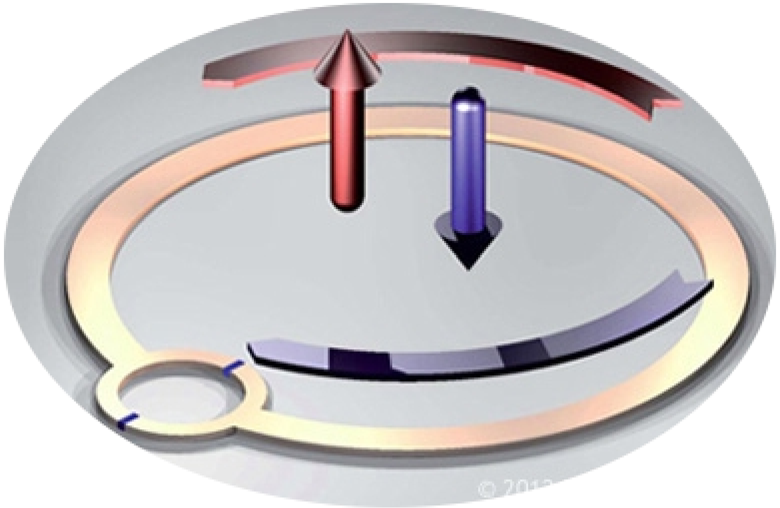
- The real manufactured qubits are far from the ideal reliable logical qubit
- Error-correction can be done by spreading the information of a single logical qubit to multiple entangled physical qubits
- With the current error rates, hundreds or thousands of physical qubits are needed to represent one fault-tolerant logical qubit



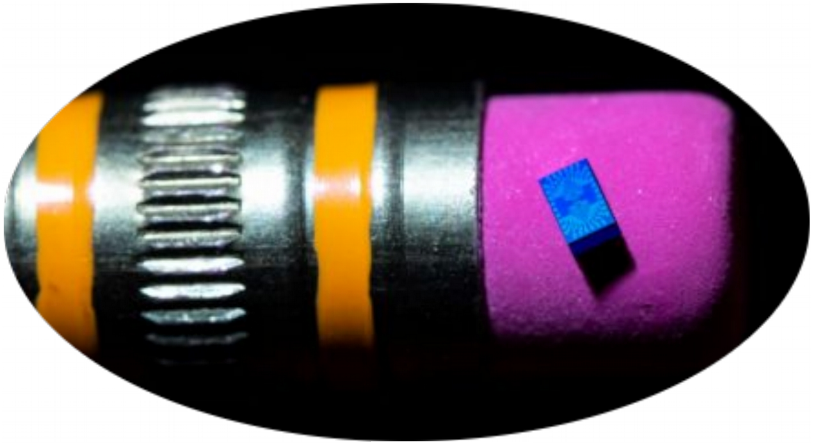
Credit: IBM

The physical qubit

- In principle any two-level quantum system can be a qubit
- Good qubit should be scalable, have a good inter-qubit connectivity, respond to manipulation, resistant to disturbances and capable of maintaining a superposition state long enough
- Most promising candidates seem to be superconducting loops and quantum dots



Credit: D-Wave systems



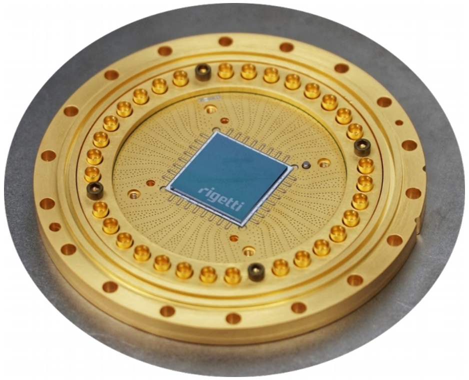
Credit: Intel Corporation/Walden Kirsch

Current situation

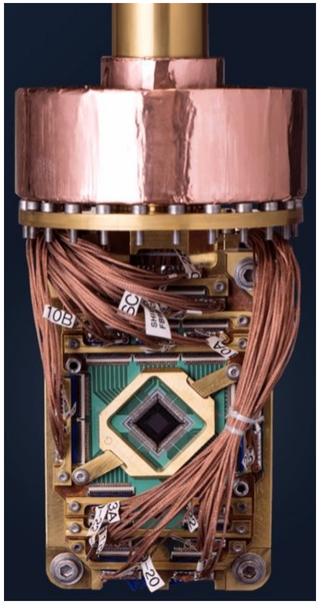
- Noisy Intermediate Scale Quantum (NISQ) Era
  - All current machines are at a proof-of-concept level, no real advantage over classical supercomputers yet
- Companies are giving access to their quantum system to benefit from crowdsourcing and to offer practice in quantum programming

IBM: 50 qubits

Google: 72 qubits



Rigetti Computing: 128 qubits


D-Wave Systems: 2048* qubits

Quantum advantage

- Quantum advantage i.e. speed gain over classical computers is to be expected soon in specific problems
  - Simulation of particles and molecules → drug development, material science
  - Optimization problems → traffic, finances, robotics
  - Improving machine learning → less data needed to reach same confidence levels
- Most effective initial applications probably hybrids of classical and quantum computing

Main points

- The power of quantum computing comes from three quantum mechanical phenomena: superposition, interference and entanglement, that can be utilized in computing by using a two-level quantum system to encode the binary information
- Fabricating a reliable qubit is really hard because of how sensitive they are to outside influences. Many extra qubits are needed to the required error correction
- Currently quantum computers are at a proof-of-concept level, where the qubits are too few and too error-prone to outperform classical supercomputers
- Quantum advantage could be reached in few years and quantum supremacy in few decades(?)

Thank you!

Second webinar on quantum computing in 24.5.2019. Topic:

Quantum computing by a Quantum Annealer

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