ΝΑΝΟΗΛΕΚΤΡΟΝΙΚΗ & ΚΒΑΝΤΙΚΕΣ ΠΥΛΕΣ

1η Διάλεξη

Βιβλιογραφία:

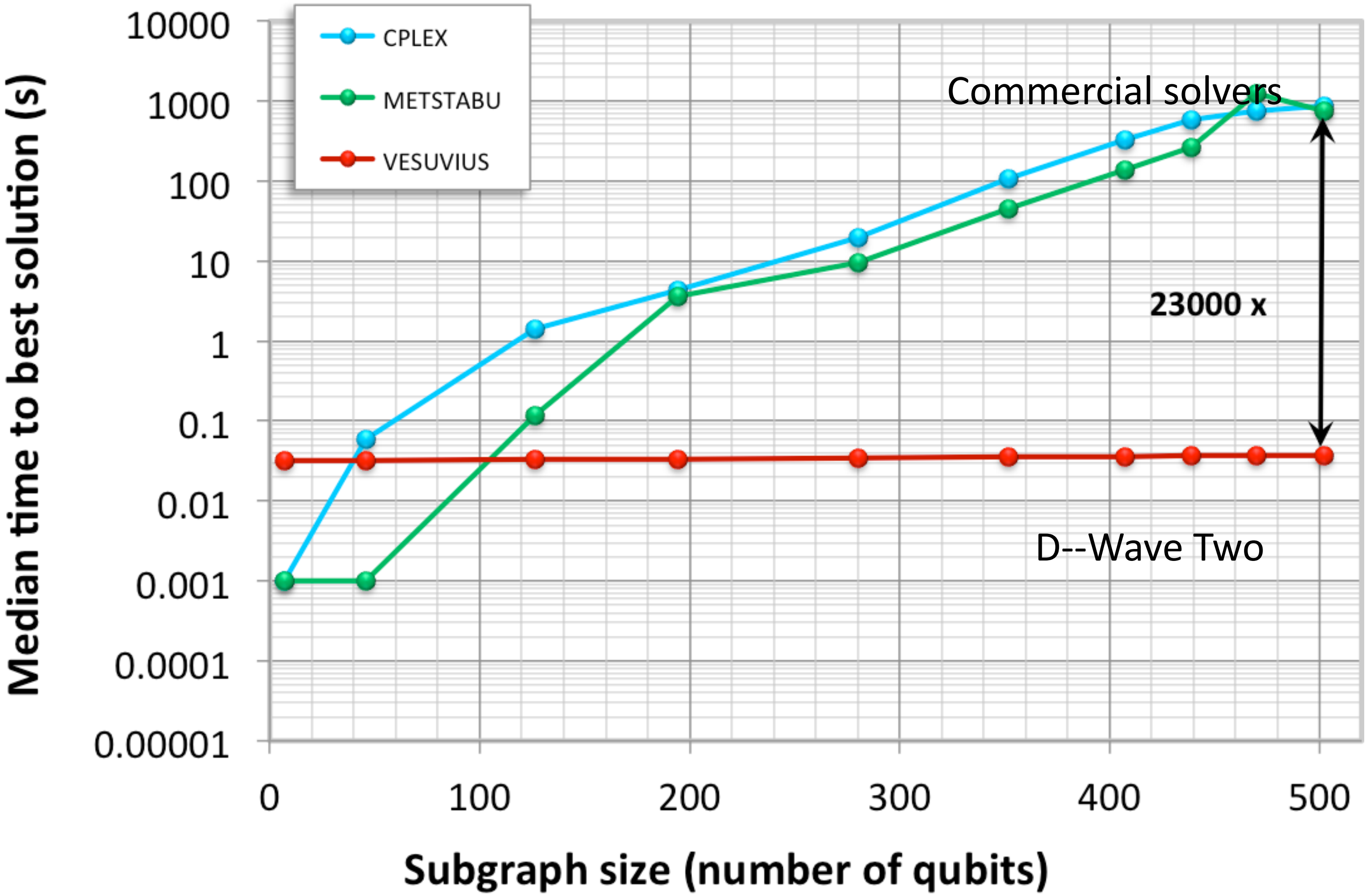
1. EXPLORATIONS IN QUANTUM COMPUTING, Colin P. Williams (2nd edition, Springer-Verlag London Limited 2011).

2. QUANTUM COMPUTING DEVICES: PRINCIPLES, DESIGNS, AND ANALYSIS, G.Chen, D.A.Church, B-G Englert, C. Henkel, B Rohwedder, M.O. Scully, M.S. Zubairy (Chapman & Hall/CRC, Taylor & Francis Group, 2007).

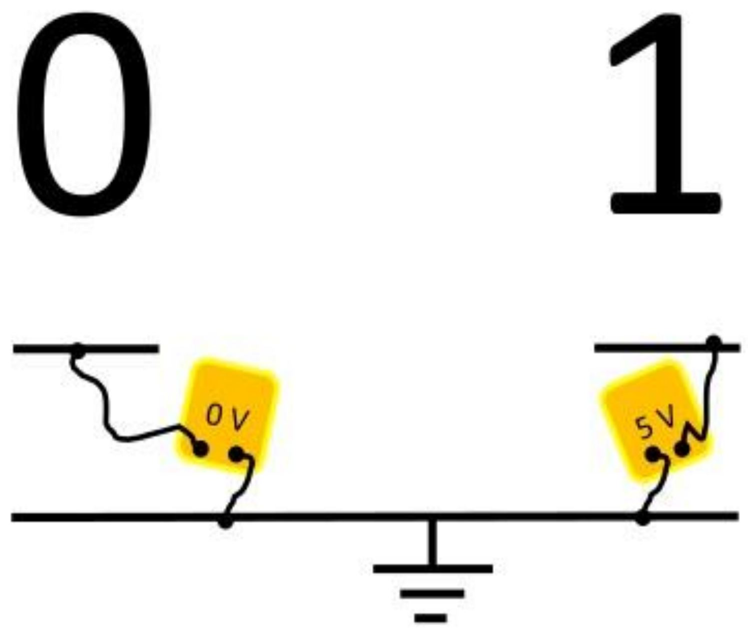
Why Build a Quantum Computer?

Median Time to Find Best Solution- Timing Benchmark

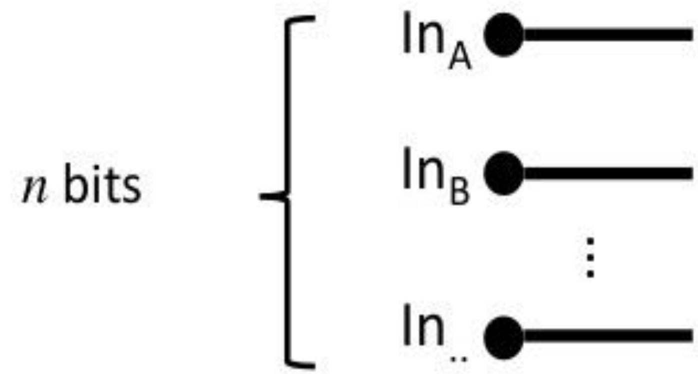
D-Wave Systems, world's first quantum computing company



Bits



Bit Registers

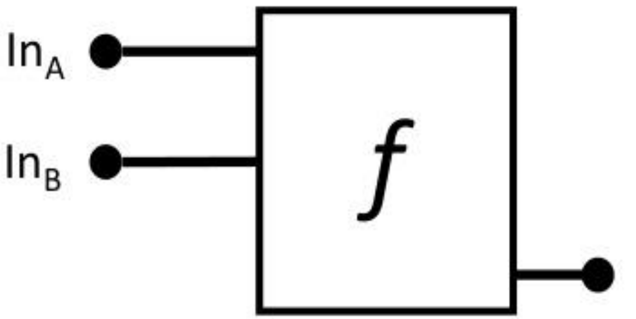


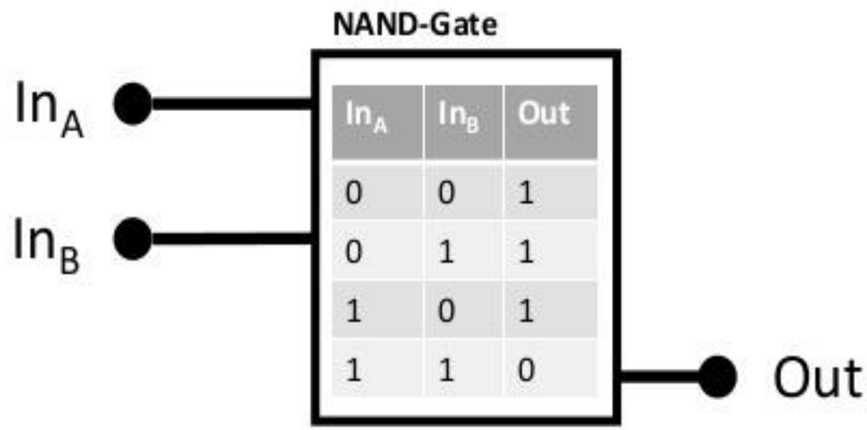
$N = 2^n$ states

$$\overbrace{0 \ldots 00, 0 \ldots 01, \ldots, 1 \ldots 11}$$

Logic Gates

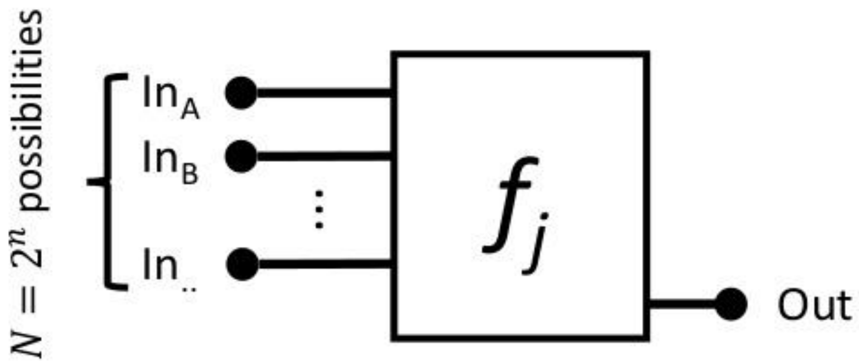
Universal Gates are Non reversible





In_A	In_B	Out
0	0	1
0	1	1
1	0	1
1	1	0

A Password Checking Function



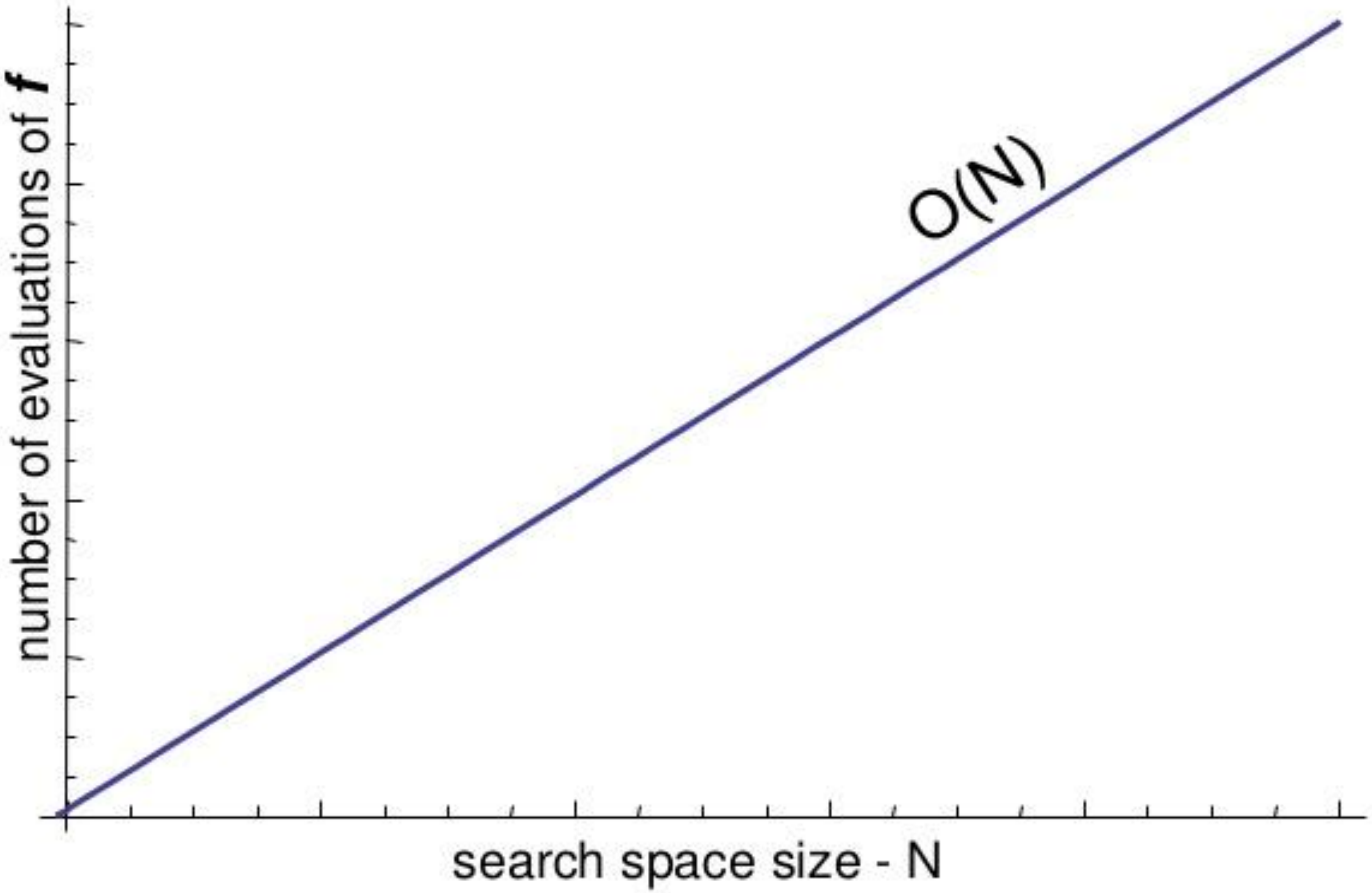
$$f = \begin{cases} 0 & i \neq j \\ 1 & i = j \end{cases}$$

$$i, j \in \{00 \ldots 000, 00 \ldots 001, \ldots, 11 \ldots 111\}$$

A Cracking Algorithm

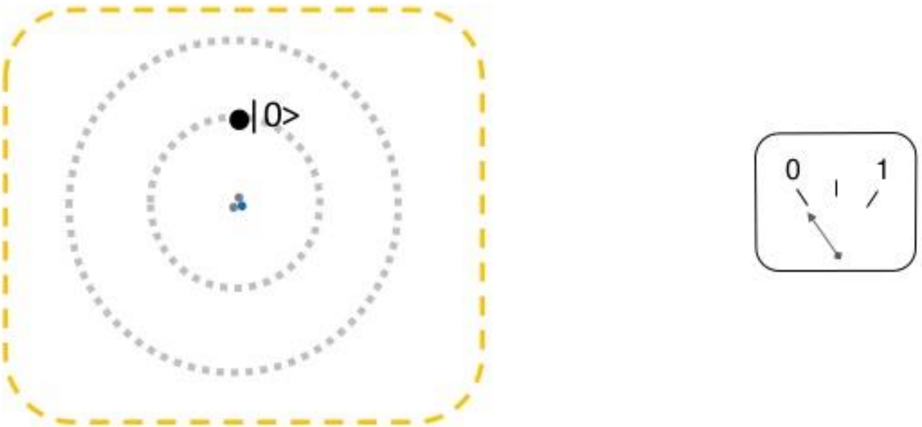
1. Set register state to $\boldsymbol{i} = \mathbf{00000...0}$
2. Calculate $\boldsymbol{f(i)}$
3. If $\boldsymbol{f(i) = 1}$, return $\boldsymbol{i}$ as solution
4. If not, increment $\boldsymbol{i}$ by $\boldsymbol{1}$ and go to (2)

Time Complexity of our Algorithm



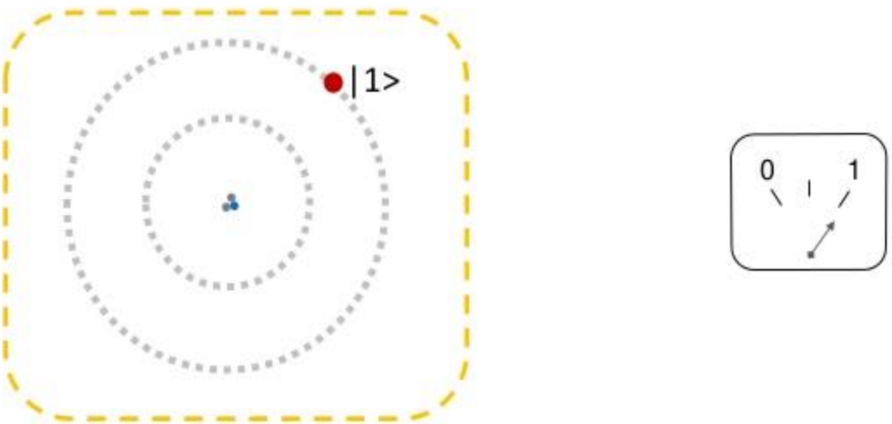
Quantum Computing

Quantum Measurements



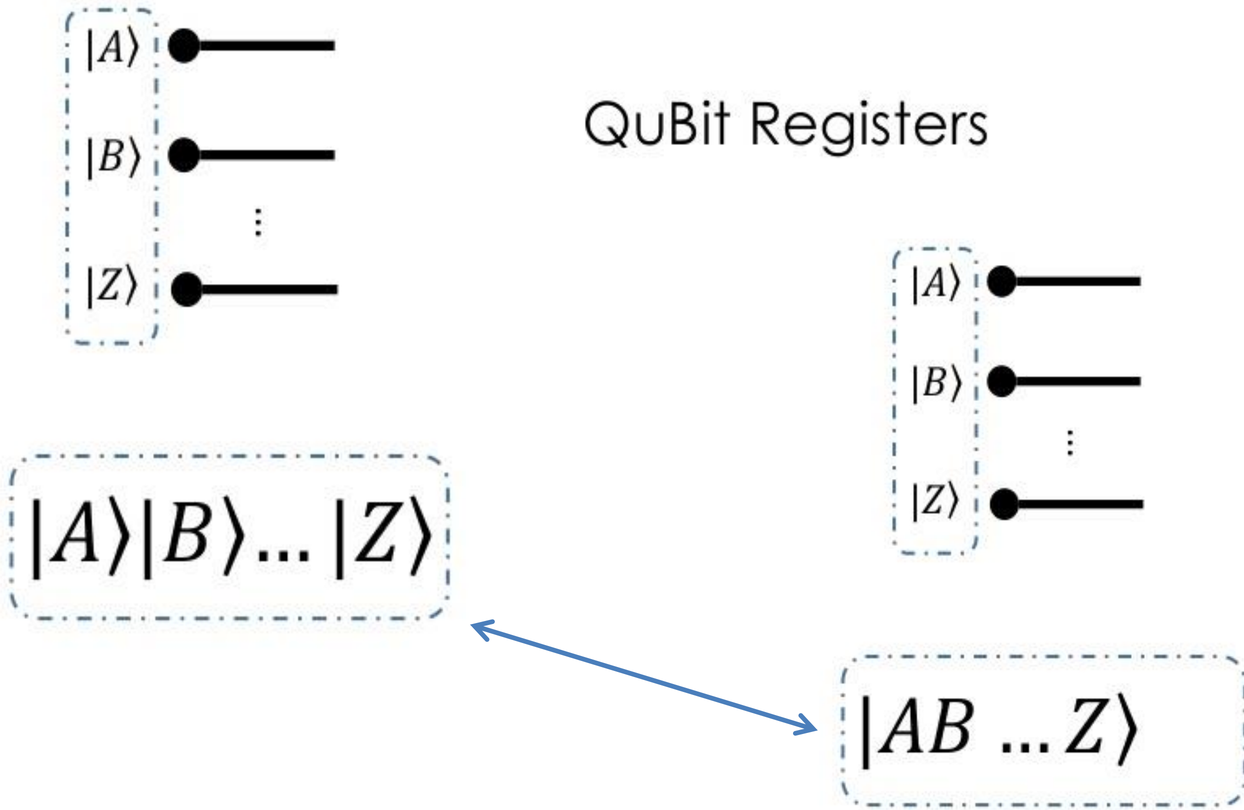
$|\psi\rangle=|0\rangle$; probability = $\boldsymbol{a}$

Quantum Measurements



$|\psi\rangle=|1\rangle$; probability = $\boldsymbol{1\text{-}a}$

QuBit Registers



Multi-Qubit Superpositions

$0.5^{1/2}(|0\rangle + |1\rangle)$

$0.5^{1/2}(|0\rangle + |1\rangle)$

$\vdots$

$0.5^{1/2}(|0\rangle + |1\rangle)$

$$0.5^{n/2}\overbrace{(|0\rangle + |1\rangle) \ldots (|0\rangle + |1\rangle)}^{\text{n times}}$$

Multi-Qubit Superpositions

$0.5^{1/2}(|0\rangle + |1\rangle)$

$0.5^{1/2}(|0\rangle + |1\rangle)$

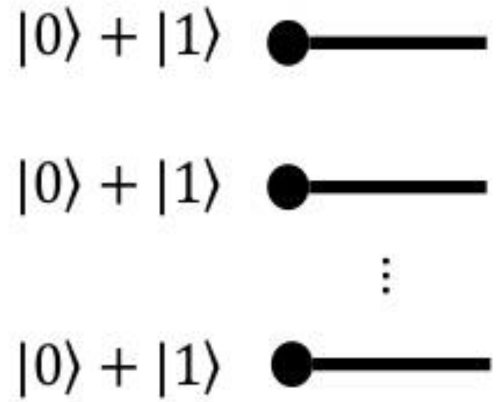
$\vdots$

$0.5^{1/2}(|0\rangle + |1\rangle)$

$$0.5^{n/2}\overbrace{(|00 \ldots 0\rangle + \cdots + |11 \ldots 1\rangle)}^{N = 2^n \text{ states in superposition}}$$

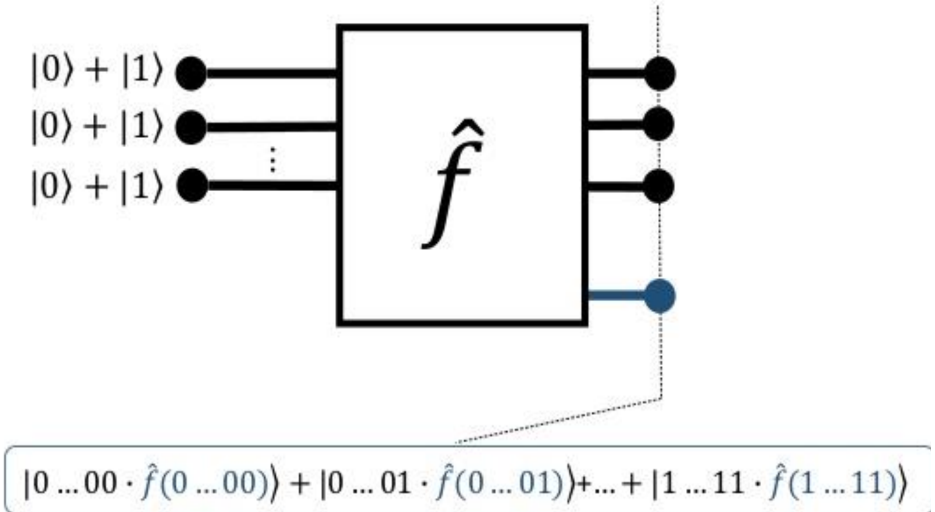
Multi-Qubit Superpositions

omitting normalizations

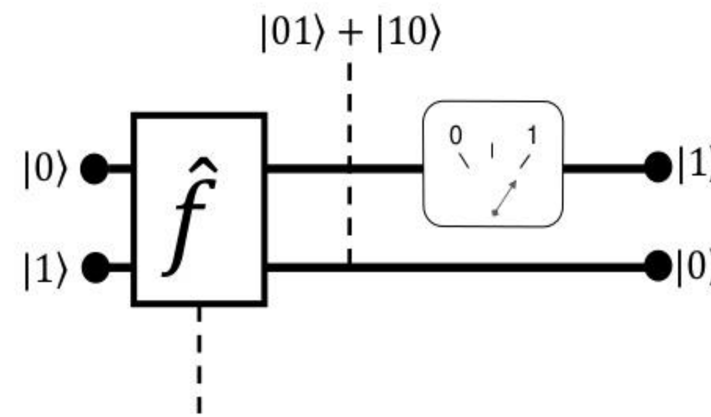


$$|00 \ldots 0\rangle + \cdots + |11 \ldots 1\rangle$$

Quantum Gates



Quantum Entanglement



$$\hat{f}(|01\rangle) = |01\rangle + |10\rangle$$

Summary: Qubits

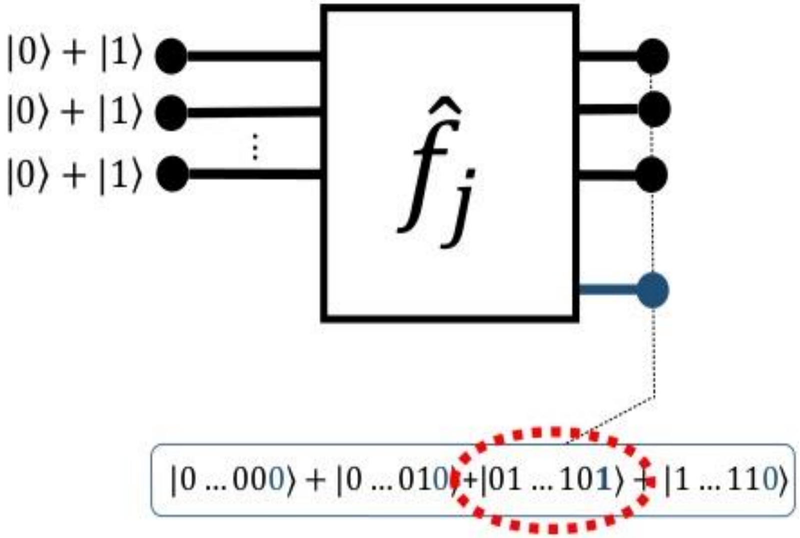
Quantum-mechanical **two-level system**

Can be in a **superposition** state $|\mathbf{0}\rangle + |\mathbf{1}\rangle$

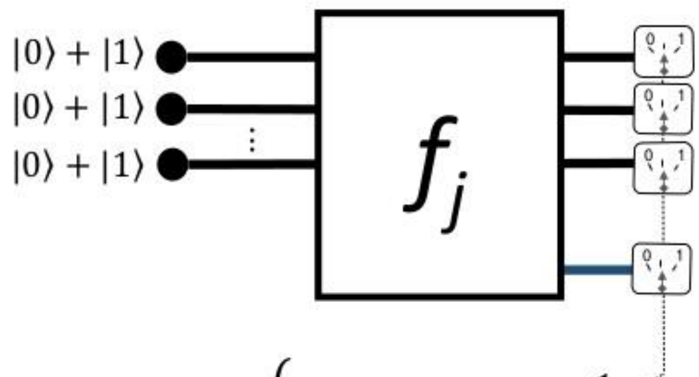
A measurement will yield either $\mathbf{0}$ or $\mathbf{1}$ and **project** the qubit into the respective state

Can become **entangled** with other qubits

Quantum Searching our Password



But how we get the solution?



$$result = \begin{cases} 01 \ldots 10\mathbf{1} & p = \dfrac{1}{N} \\ ** \cdots ** \, \mathbf{0} & p = 1 - \dfrac{1}{N} \end{cases}$$

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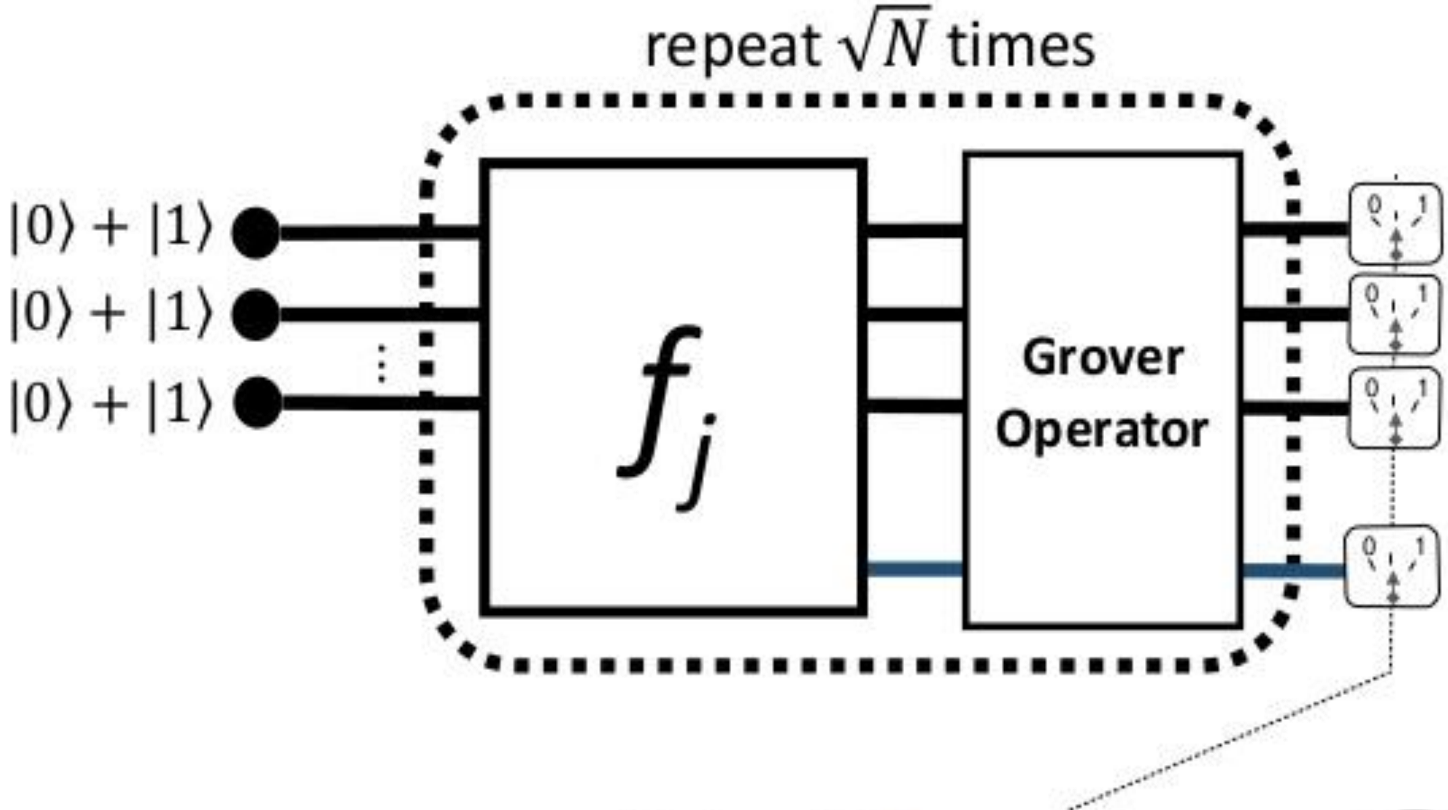
Solution: Grover Algorithm



$$result = \begin{cases} 01 \ldots 10\mathbf{1} & p \approx 1 \\ ** \cdots ** \mathbf{0} & p \approx 0 \end{cases}$$

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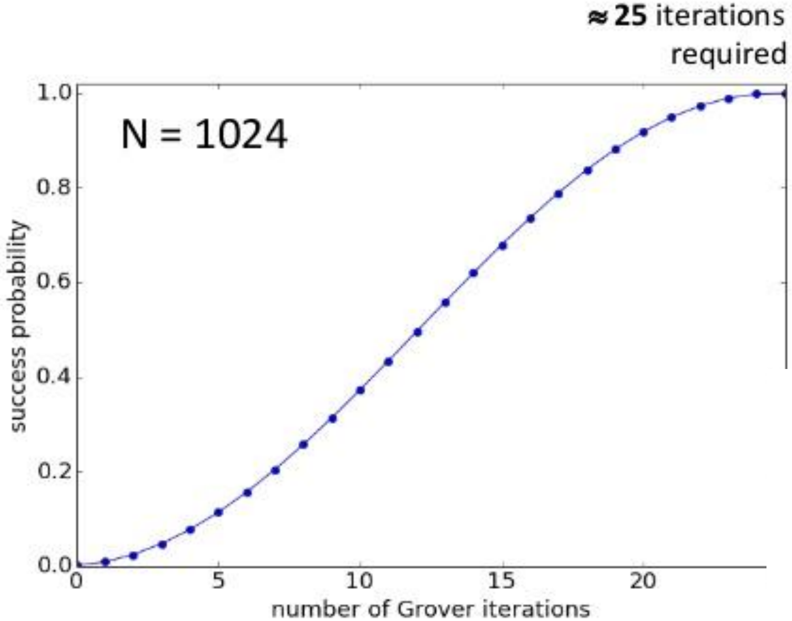
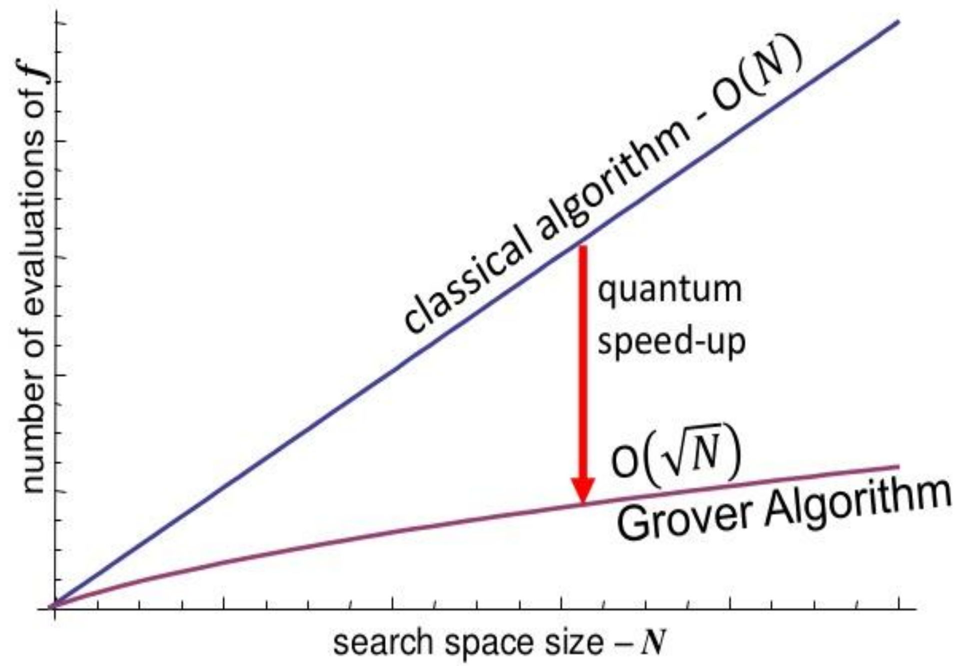
Grover L.K.: A fast quantum mechanical algorithm for database search, Proceedings, 28th Annual ACM Symposium on the Theory of Computing, 1996

Efficiency of Grover Search
(for 10 qubits)

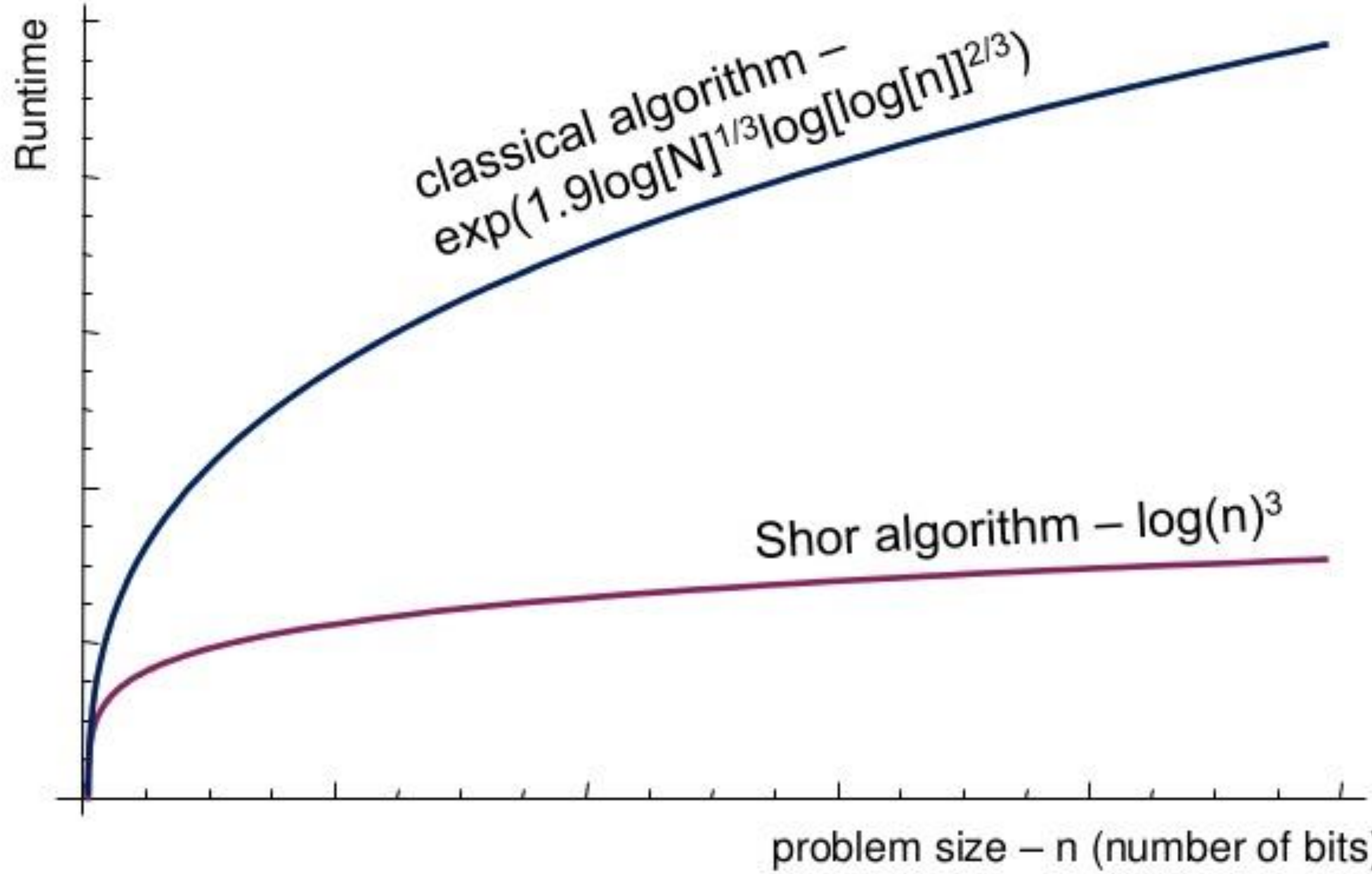


Time Complexity Revisited



Number Factorization: Shor Alg.

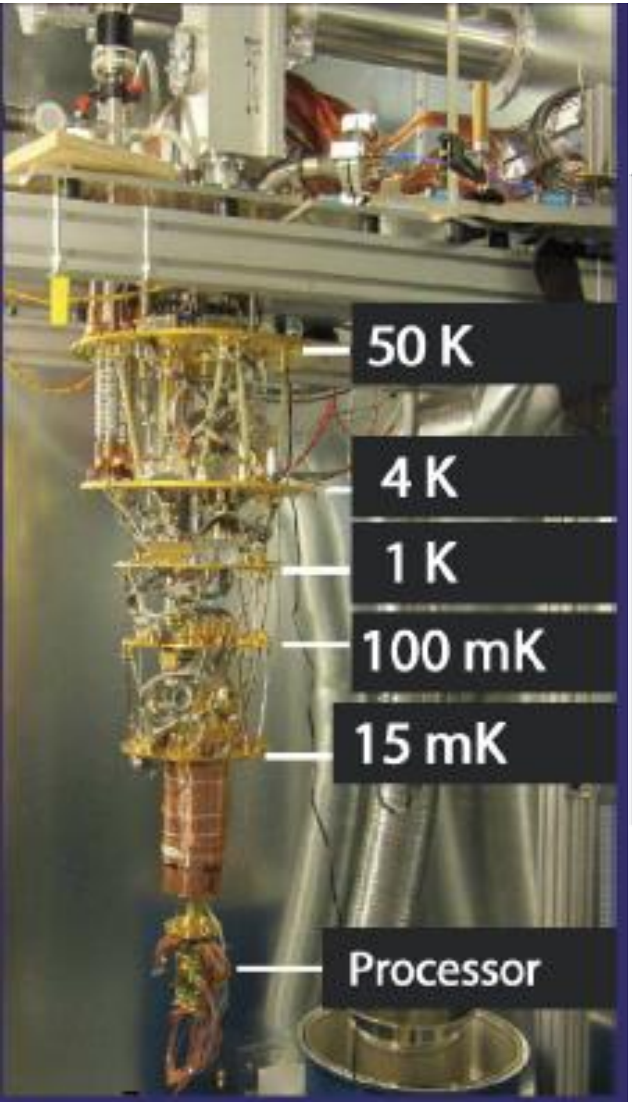
$r = q \cdot s$; q,s prime numbers

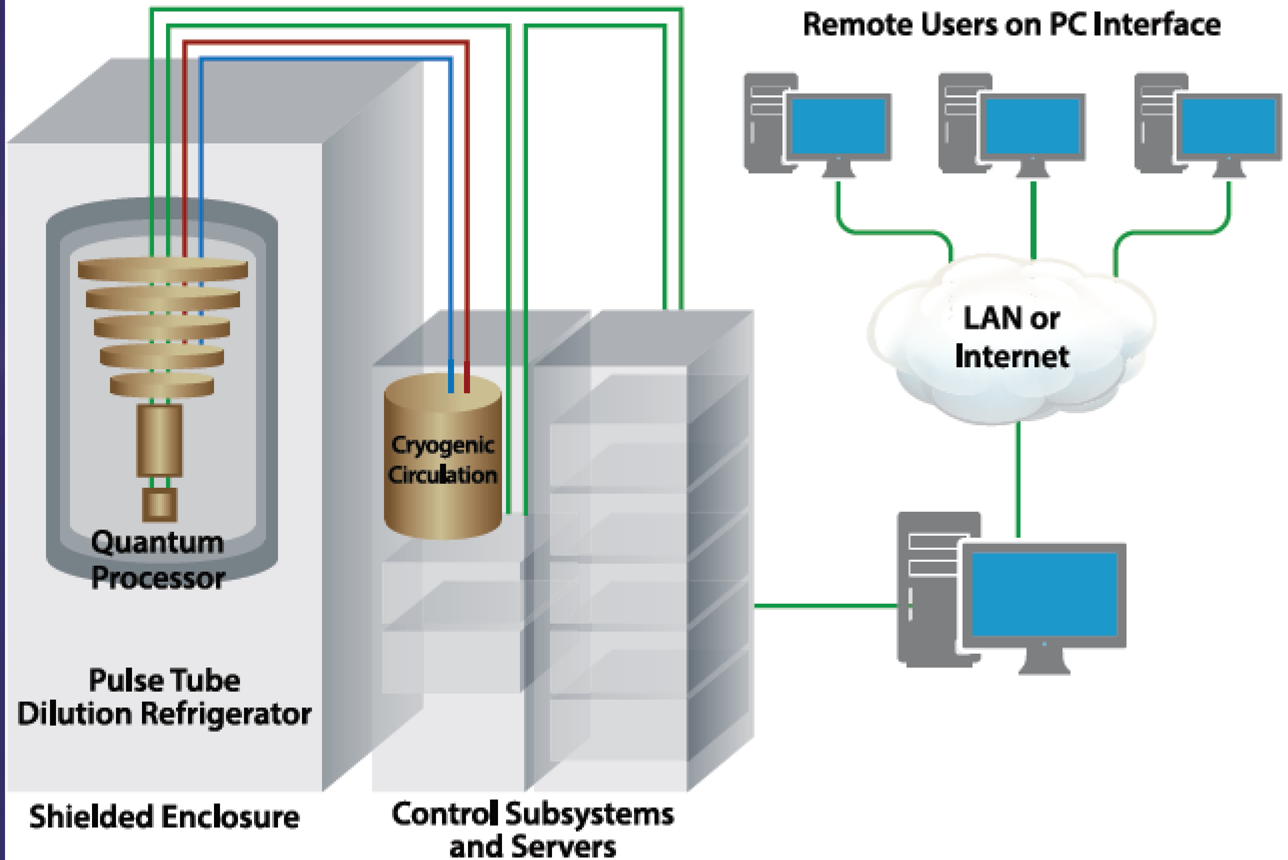


D-Wave Systems is the world's first quantum computing company

Reducing the temperature of the quantum processor to near absolute zero is required to isolate it from its surroundings so that it can behave quantum mechanically.

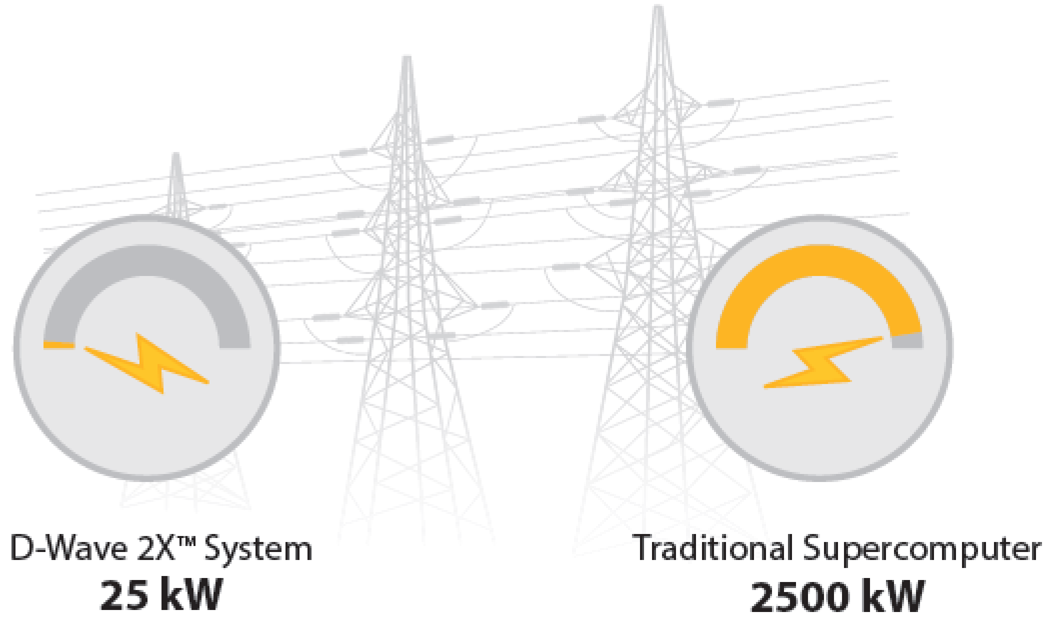
The system sits inside a shielded enclosure that screens out RF electromagnetic noise. The only path for signals between the inside and outside of the shielded enclosure is a digital optical channel carrying programming information in, and results of computations out.





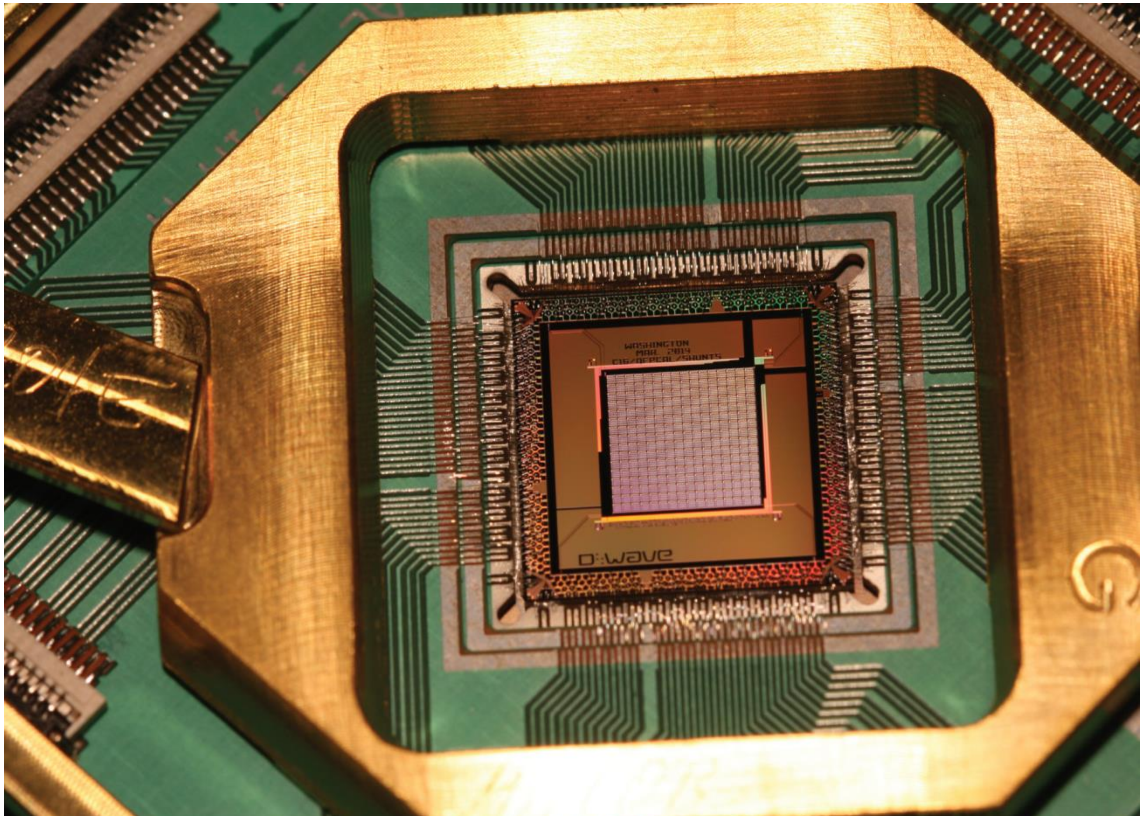
Power and Cooling

The system requires water cooling, but the amount of water needed is on par with what a kitchen tap can provide. The amount of air conditioning needed is a tiny fraction (1/10) of what would be expected in a data center.

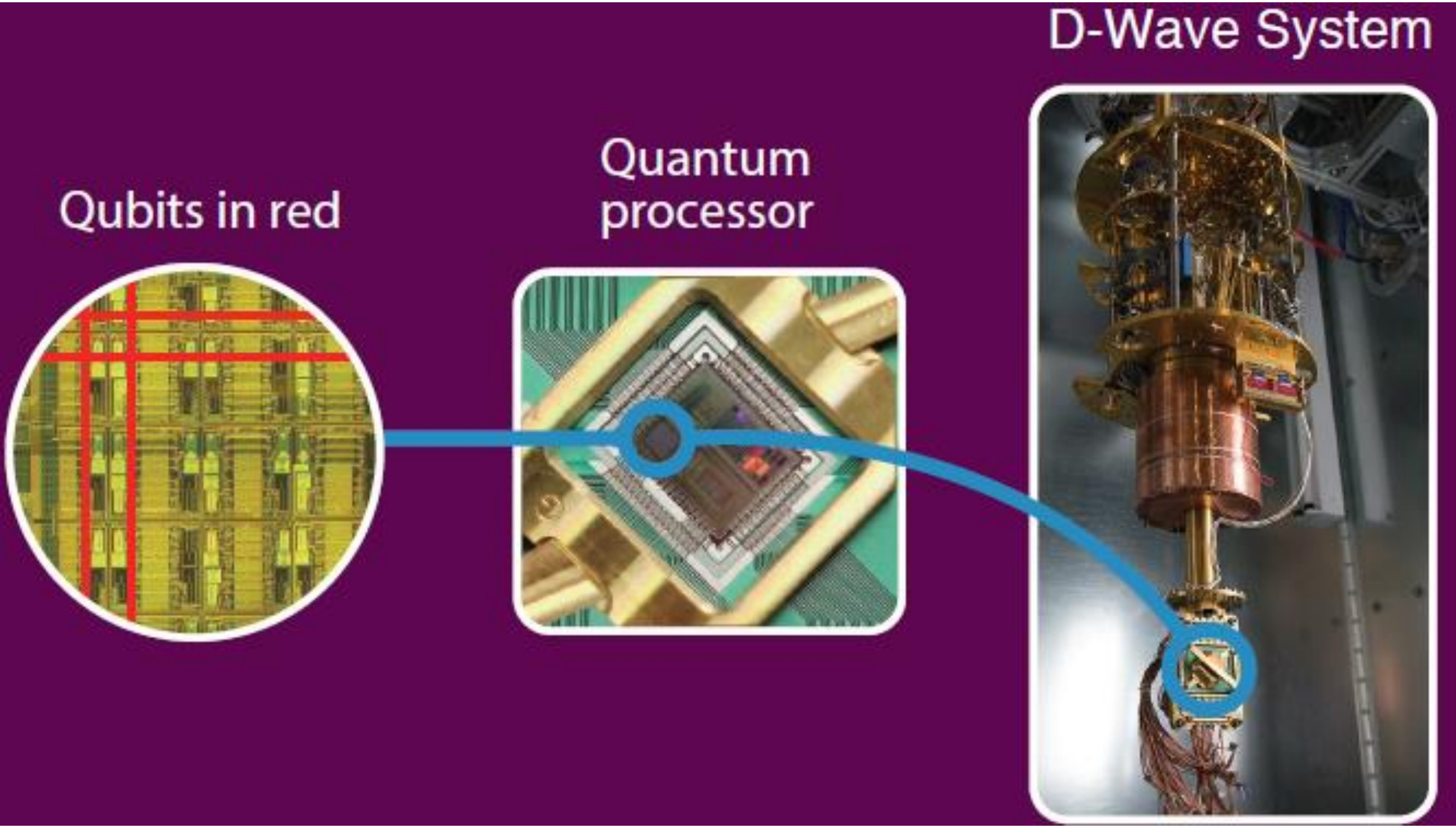


The Quantum Processor

is built from a lattice of tiny loops of the metal niobium, each of which is one quantum bit, or qubit. When niobium is cooled down below 9.2 Kelvin it becomes a superconductor and starts to exhibit quantum mechanical effects. By circulating current either clockwise or counter-clockwise, the superconducting qubit emits a magnetic field pointing downward or upward, encoding a logical 1 or 0.



The D-Wave 2X system is based on a fabric of 1000+ qubits and over 3000 couplers. In order to attain this scale the processors contain over 128,000 Josephson Junctions - believed to be the most complex superconductor integrated circuits ever built.



Software and Programming

- The D-Wave 2X System has a web API with client libraries available for C, C++, Python and MATLAB. This interface allows the machine to be easily accessed as a cloud resource over a network. Using development tools and client libraries, users can write code in the language of their choice.

- Values corresponding to the "weights" of the qubits and coupling "strengths" of the interaction between them are submitted to the system, which then executes a single Quantum Machine Instruction (QMI) for processing.

- The solutions are values that correspond to the optimal configuration of qubits found, or the lowest points in the energy landscape. These values are returned to the user program over the network.

- Because a quantum computer is probabilistic rather than deterministic, multiple values can be returned, providing not only the best solution found but also other very good alternatives from which to choose. Users can specify the number of solutions they want the system to return.

D-Wave Software Environment