Quantum Computing

Concepts and Low-Level APIs

Review

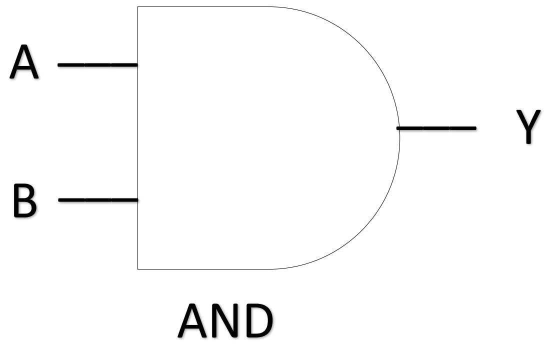
- Quantum Computers are fundamentally different
  - IPO (just like classic), but P = quantum operations
  - Quiet environment (near absolute zero temperature)
- Expect Quantum Cloud Services first
- Shor’s Algorithm could “break” today’s encryption algorithms
  - Integer factorization that can run in polynomial time (instead of exponential)

Classic Computers: Low-level questions

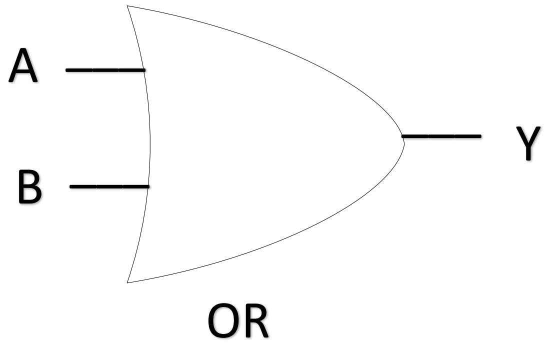
- Where are transistors are used in your computer?
  - Bell Labs, 1947
- What is a semiconductor?
- What is quantum tunneling?

- Immature hardware? Low-level APIs

Classic Gates

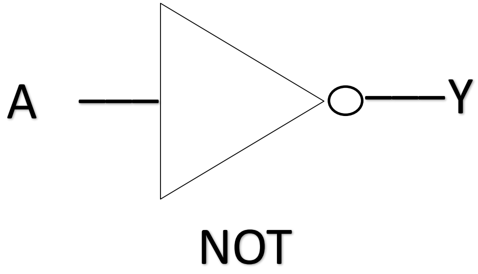


A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

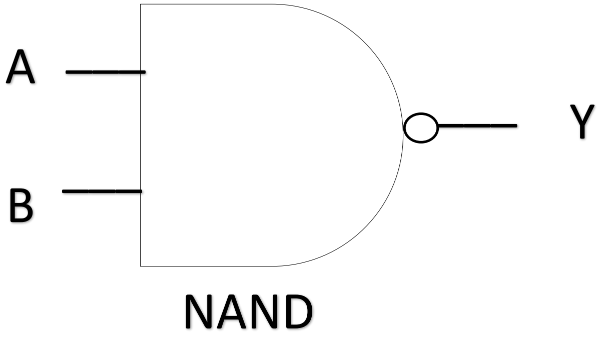


A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

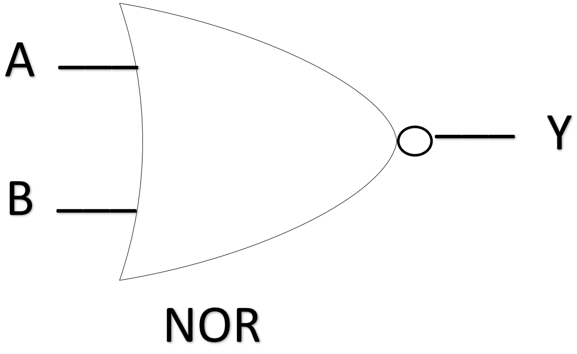
Classic Gates



A	Y
0	1
1	0



A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0



A	B	Y
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0	1	0
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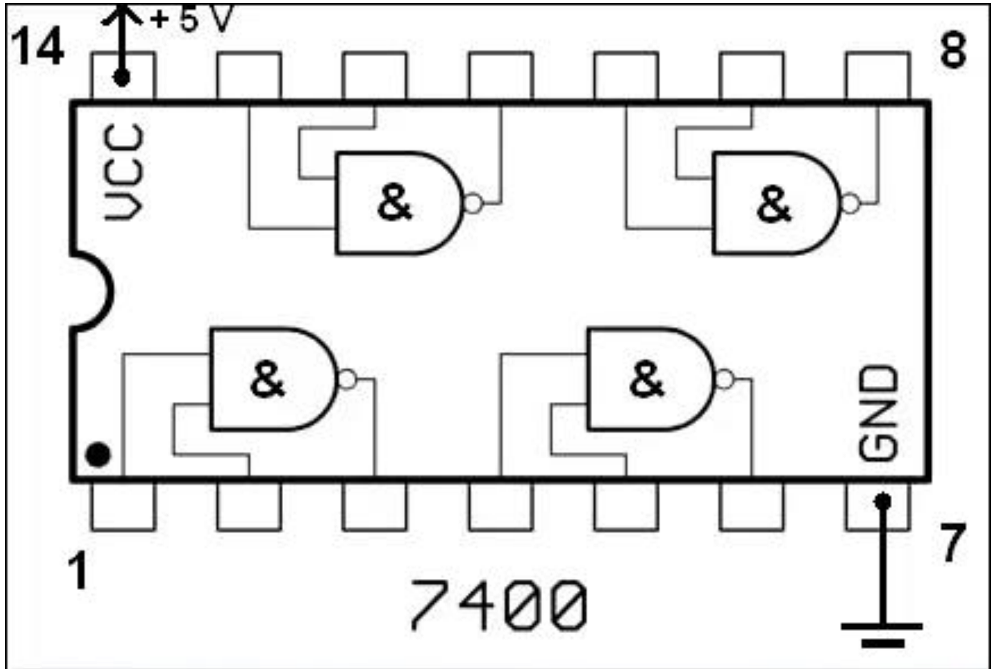
1	1	0



14
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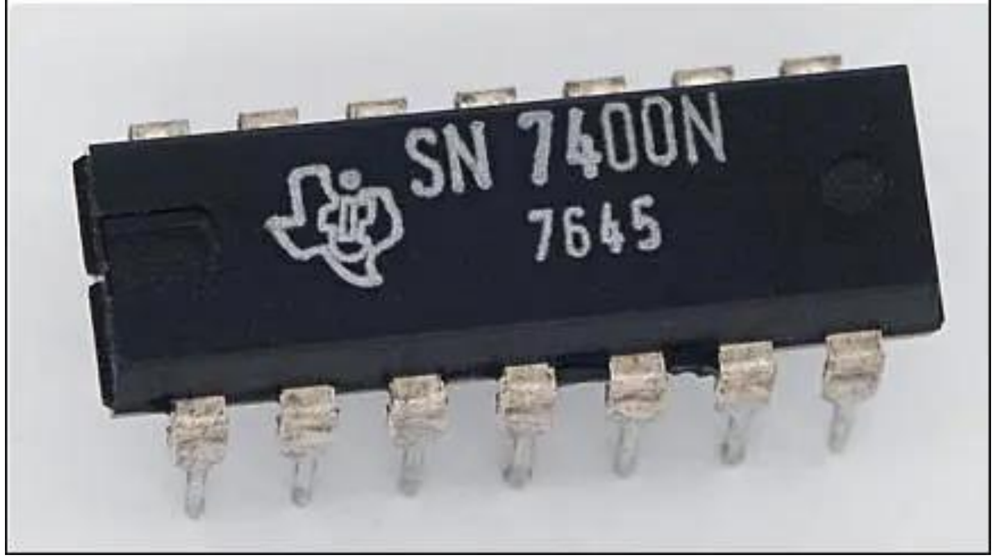

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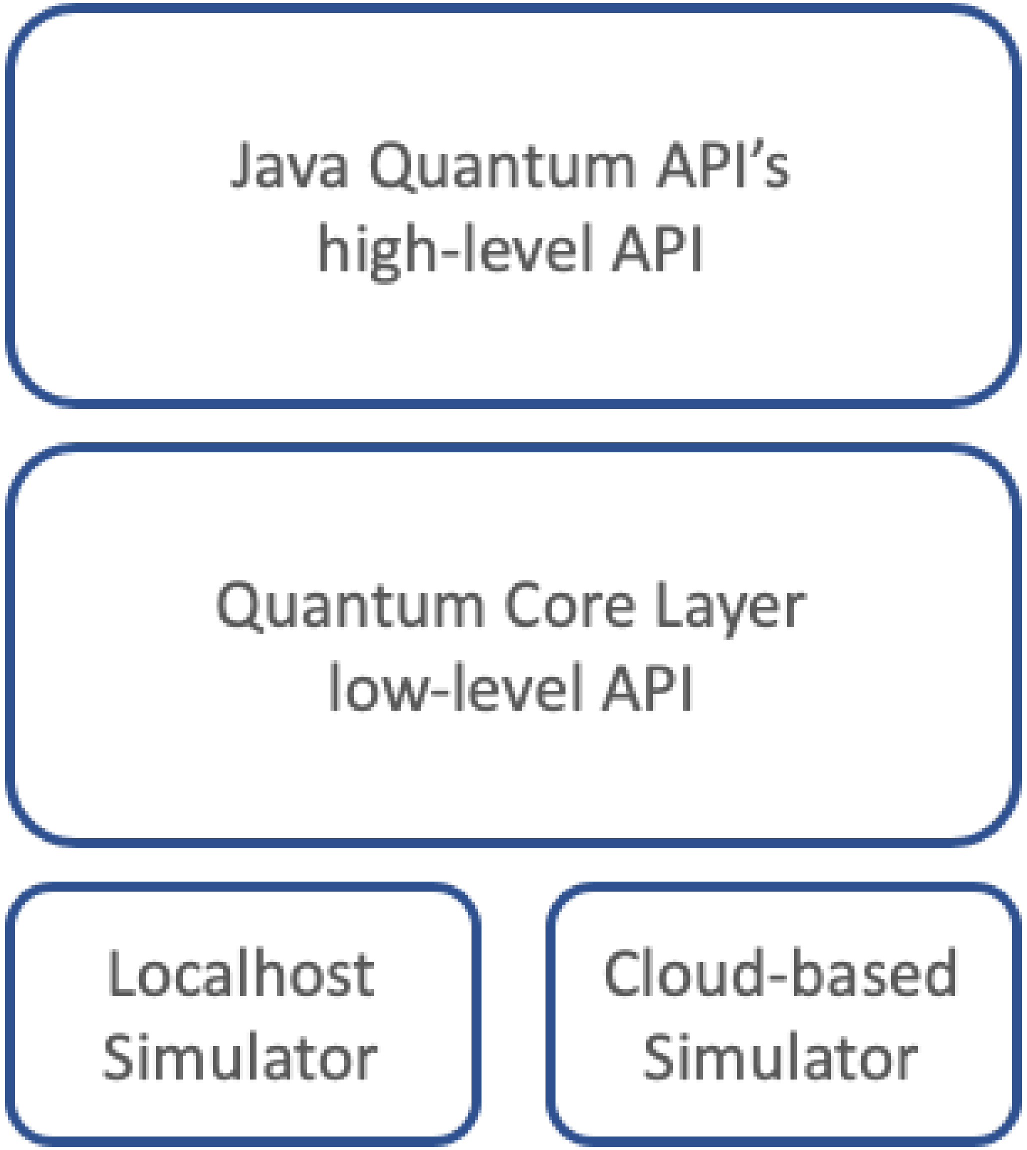
Strange

- Johan Vos, PhD
- Quantum Computing in Action, 2022
- Open Source
- Library with a Java API
- Maven & Gradle Build Tool Support
  - Eclipse
  - NetBeans
  - IntelliJ



Classic Bit vs Qubit

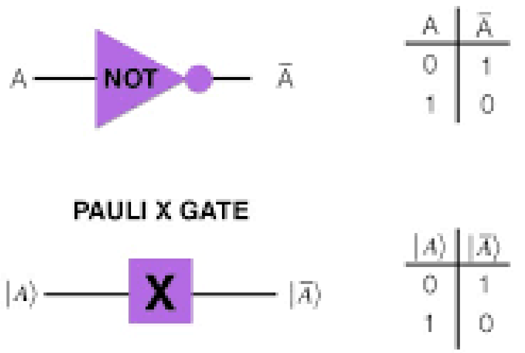
- Hold 0 or 1
- Measure: results in 0 or 1
- Single value: 0 or 1

- Hold 0 or 1
- Hold combinations of 0 and 1
- Measure: results in 0 or 1
- Single vector

$$|0> = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$|1> = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Pauli-X Gate



X |0> = |1>

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

X |1> = |0>

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

Description	Code (Q# and QuTiP)	Unitary matrix

Bit flip (Pauli X)	X(target); // Q#
	qt.sigmax() # QuTiP
		$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$

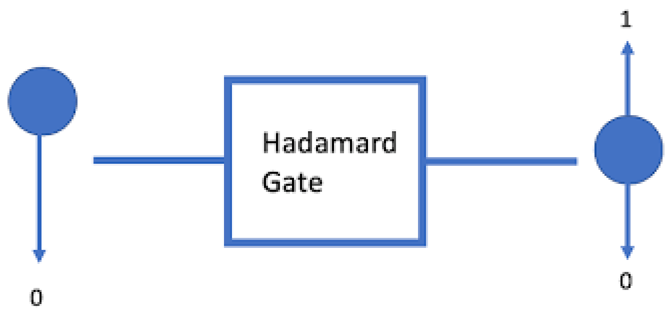
source: Learn Quantum Computing with Python and Q# Kaiser & Granade

Flip a Qubit with a Pauli-X Gate

- Create Environment
- Create a Program w/ 1 Qubit (Value is 0 by default)
- Create a Step
- Add an X gate to the step
- Add the step to the program
- Run the program
- Get all Qubits from the Result (only 1 qubit at position 0)
- Measure and display

```java
public static void main(String[] args) {
    QuantumExecutionEnvironment env = new
    SimpleQuantumExecutionEnvironment();
    Program prog = new Program(1);
    Step step = new Step();
    step.addGate(new X(0));
    prog.addStep(step);
    Result r = env.runProgram(prog);
    Qubit[] qubits = r.getQubits();
    Qubit zero = qubits[0];
    int value = zero.measure();
    System.out.println("Value = " + value);
}
```

Hadamard Gate



$$\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}$$

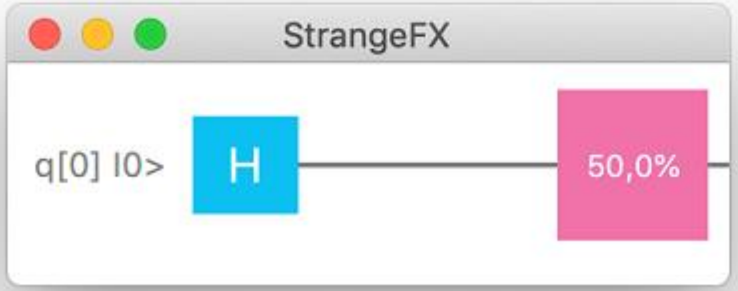
$$\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}\begin{bmatrix}1\\ 0\end{bmatrix} = \frac{1}{\sqrt{2}}\begin{bmatrix}1\\ 1\end{bmatrix}$$

- Input: qubit that holds 0
- Apply the H Gate
- Output: qubit in superposition
  - 50% chance 0 when measured
  - 50% chance 1 when measured

source: freecontent.manning.com (J. Vos)

QRNG with a Hadamard Gate

- Request one Qubit in the “ket-zero” state
- Apply the Hadamard Gate to the Qubit
- The Qubit is now in superposition
- Measure the Qubit



- Create Environment
- Create a Program w/ 1 Qubit
- Create a Step
- Add a H gate to the step
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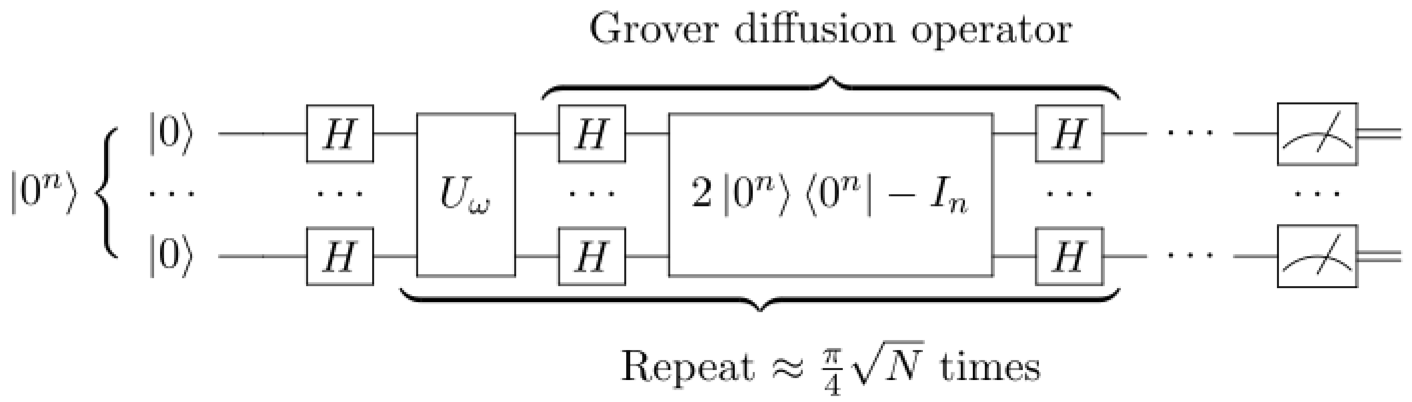
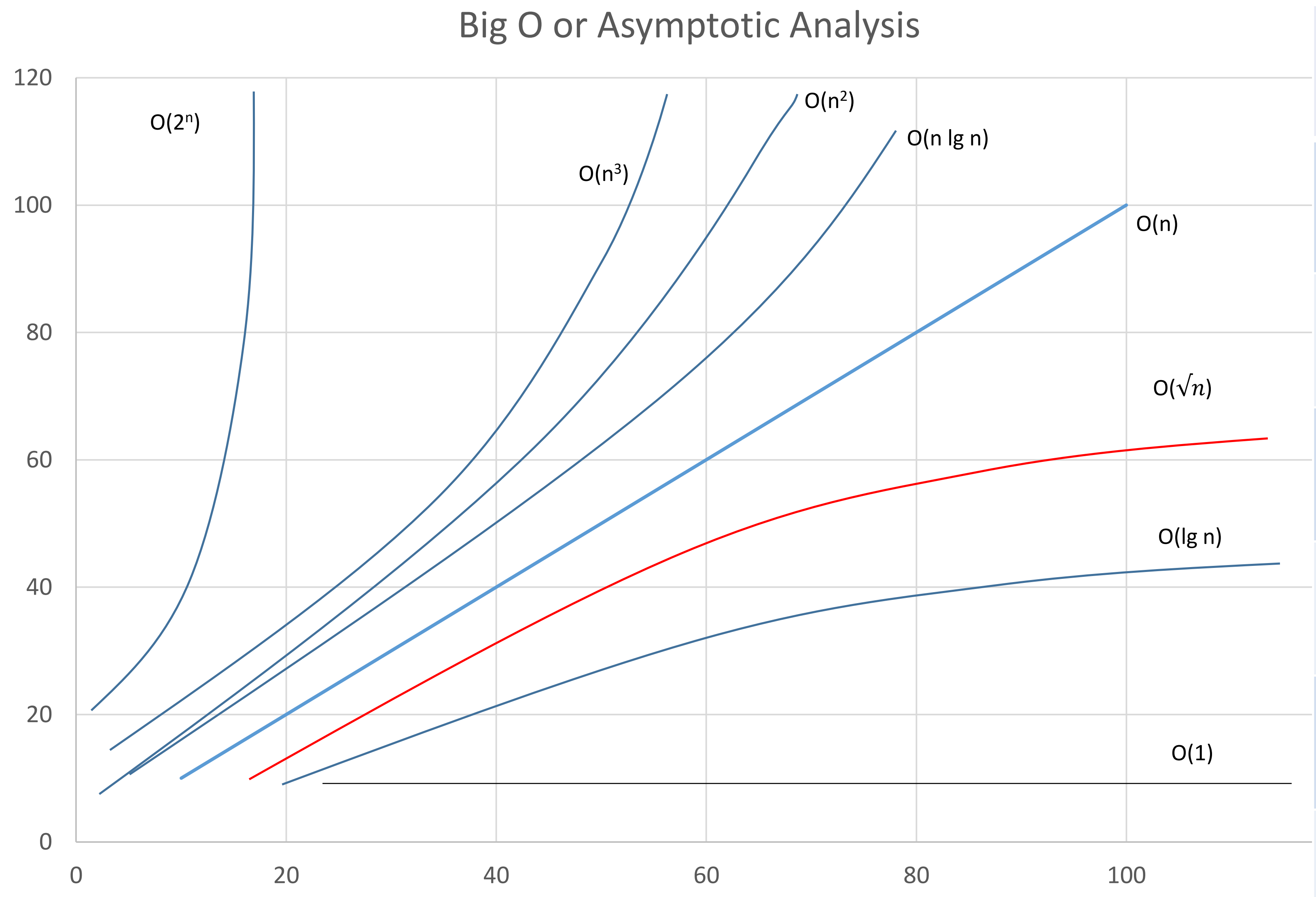
Grover's Quantum Search Algorithm

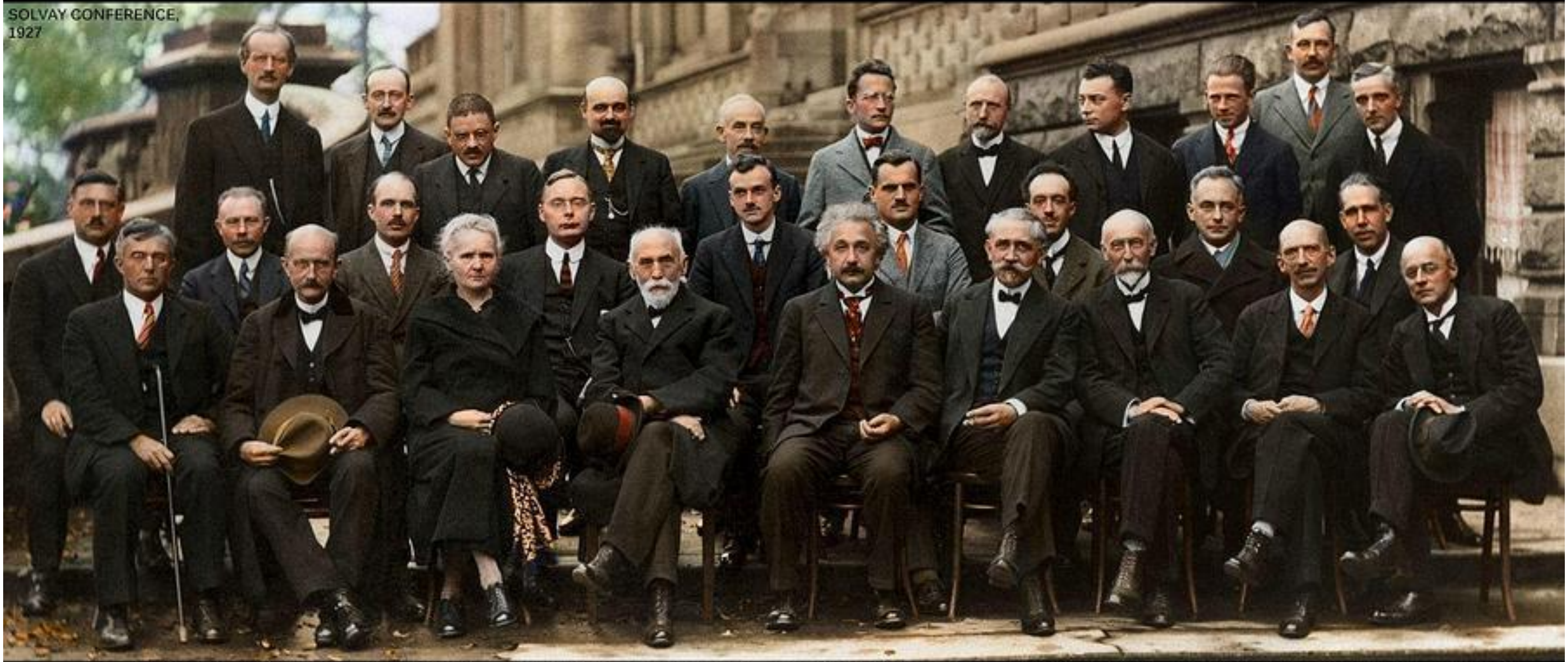
- Search unstructured data
- O(n)
- Linear Search

- Lov Grover
  - Bell Labs, 1996
- O($\sqrt{n}$)
  - First scalable, 2017





$O(1)$	Constant
$O(\lg n)$	Logarithmic
$O(n)$	Linear
$O(n \lg n)$	Log-linear
$O(n^2)$	Quadratic (Polynomial)
$O(n^3)$	Cubic (Polynomial)
$O(2^n)$	Exponential



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