Quantum Computing

Claire Yang

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Outline

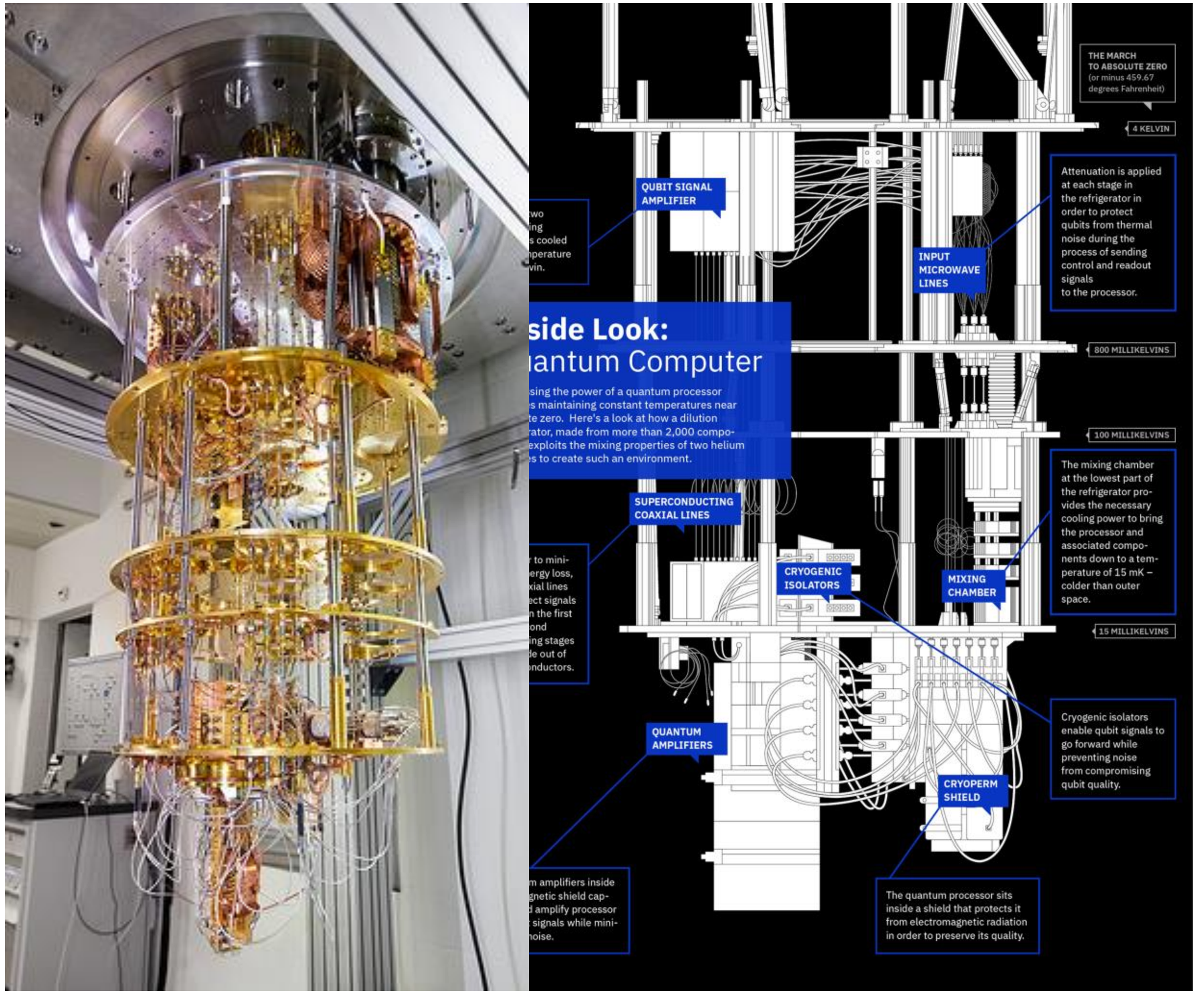
—What is a quantum computer like?

—How does quantum computing work?

—Possibilities of quantum computing

—The realization of quantum Fourier transform

What is a Quantum Computer Like



IBM's quantum computer

Companies:

Google 72-qubit

50-qubit IBM

D-Wave

rigetti

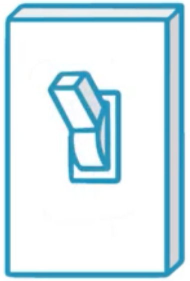
intel

Microsoft

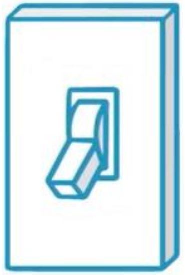
Picture from: https://www.ibm.com/blogs/research/2018/01/quantum-prizes/

How Does Quantum Computing Work

Classical computing fundamental unit: **bit** →



On: 1



Off: 0

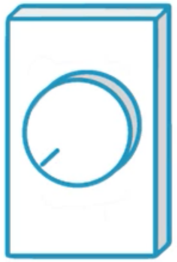
Quantum computing fundamental unit: **qubit** (**qu**atum **bit**)

→ photon

→ nucleus

→ electron

On: $|1\rangle$

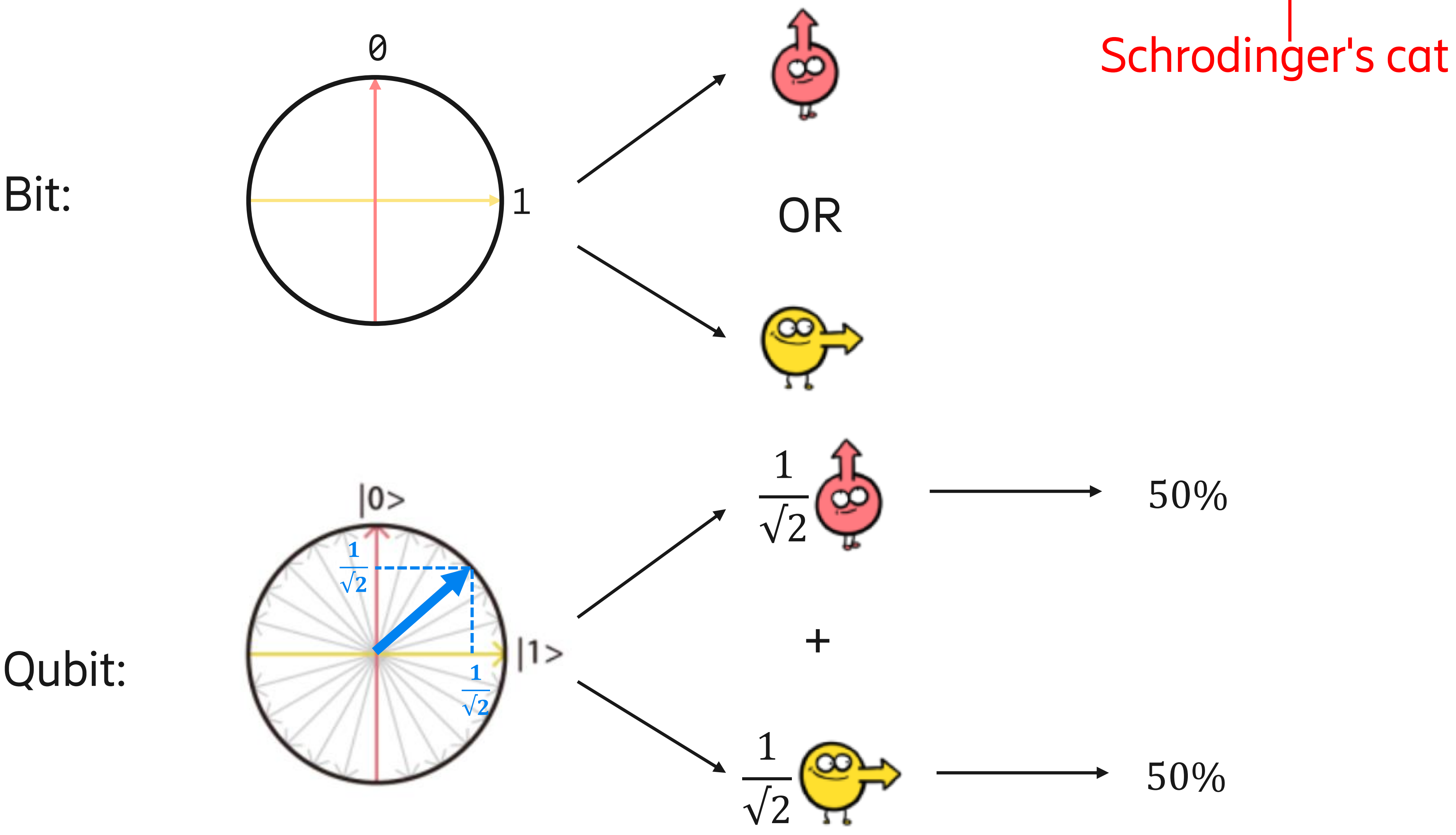


Off: $|0\rangle$

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

Picture from: https://app.pluralsight.com/library/courses/quantum-computing-big-picture/table-of-contents

How Does Quantum Computing Work: Superposition



Picture from: https://zhuanlan.zhihu.com/p/27387032

How Does Quantum Computing Work: Example

2 classical bits:

bit 1	bit 2
0	0
0	1
1	0
1	1

2 qubits:

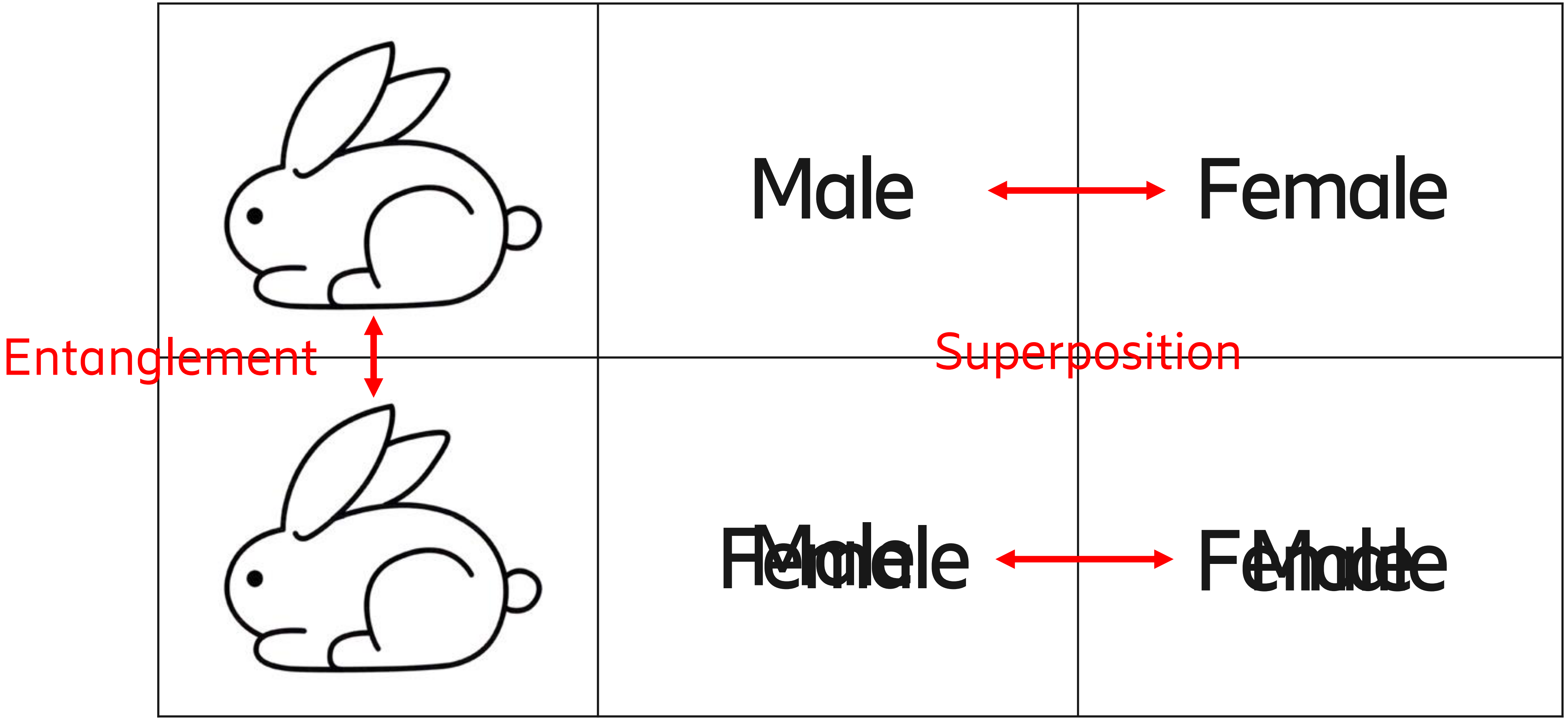
$$\alpha\,|\,00\,\rangle + \beta\,|\,01\,\rangle + \gamma\,|\,10\,\rangle + \delta\,|\,11\,\rangle$$

(qubit 1, qubit 2)

2 qubits contain 4 bits of information.
N qubits contain 2^N bits of information.

300 qubits → ~2,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000 bits

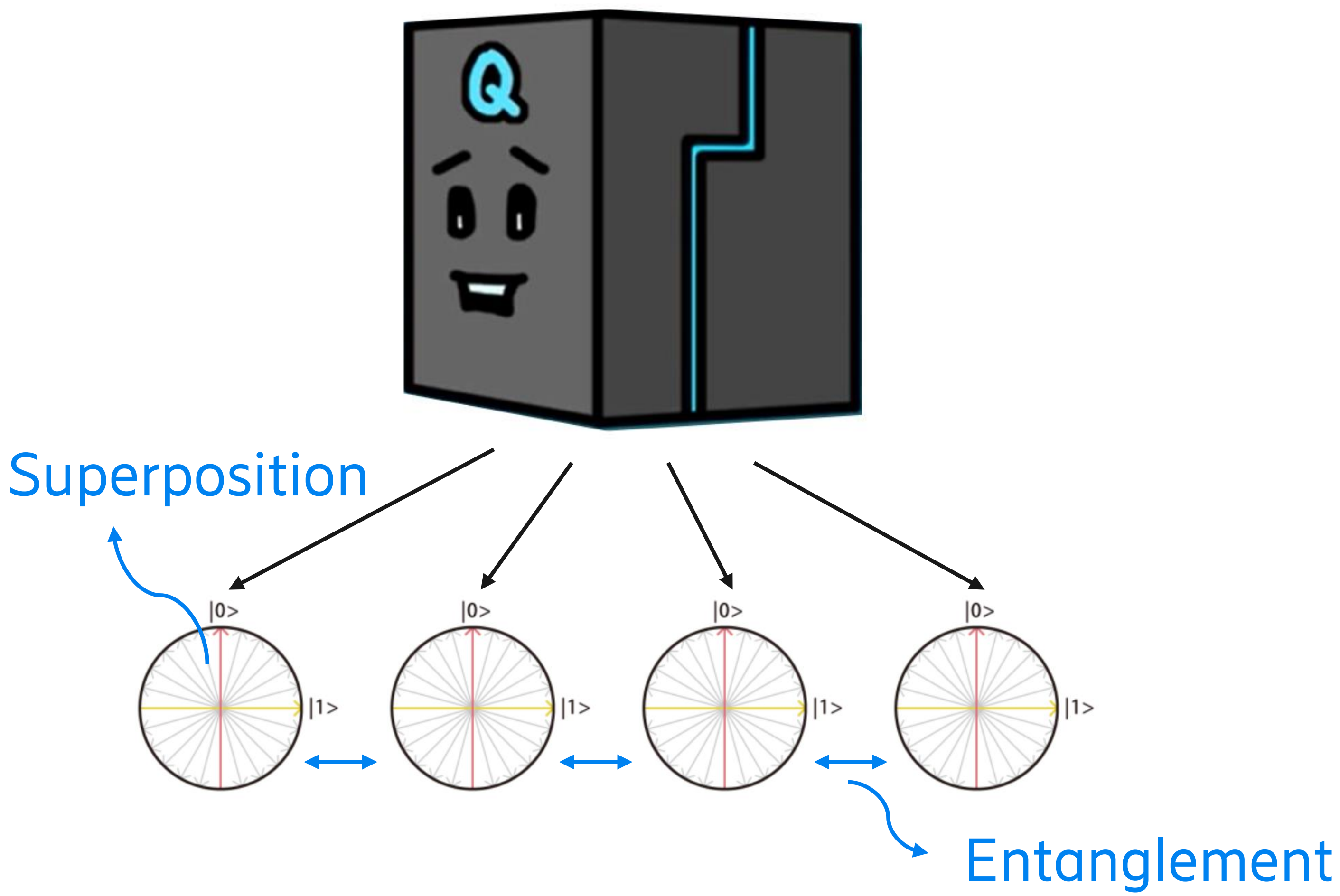
How Does Quantum Computing Work: Entanglement



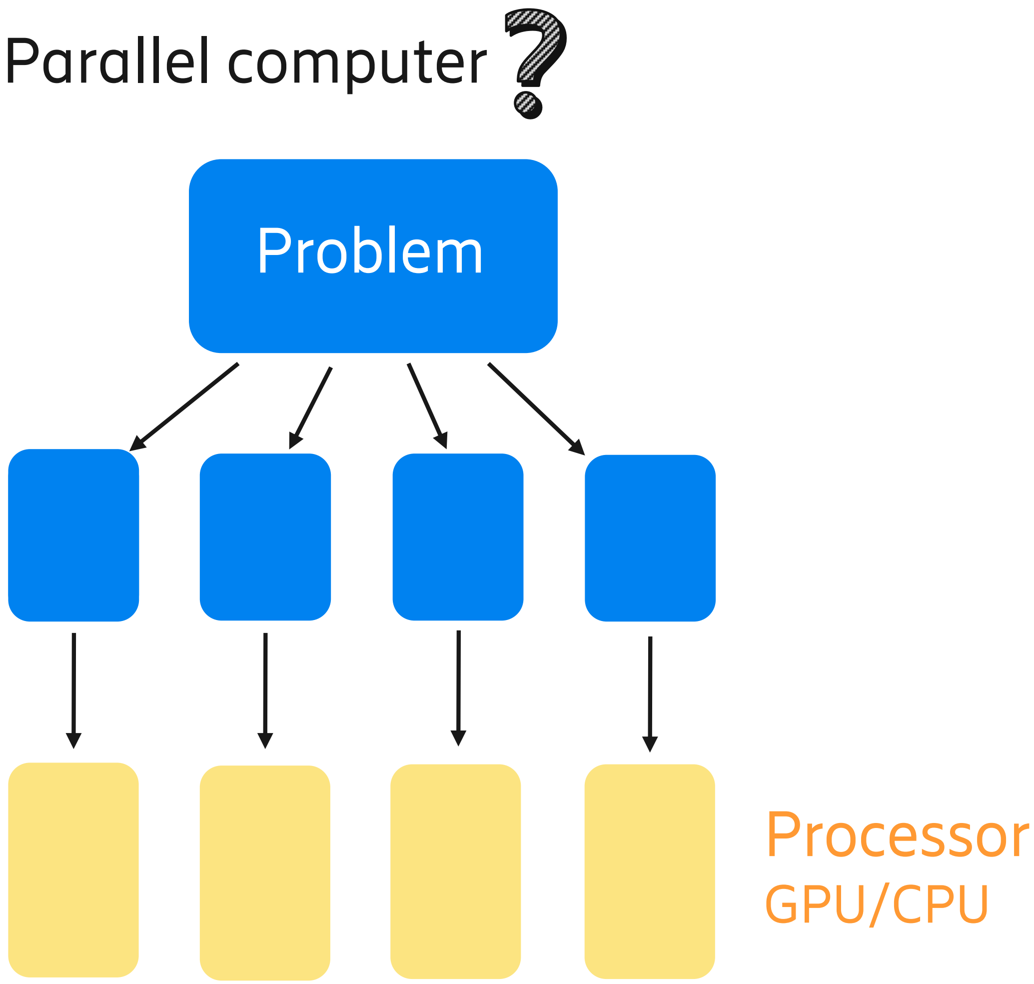
Picture from: http://et.27270.com/jbh/ktjbh/5241.html

How Does Quantum Computing Work

Quantum computer



Parallel computer ?

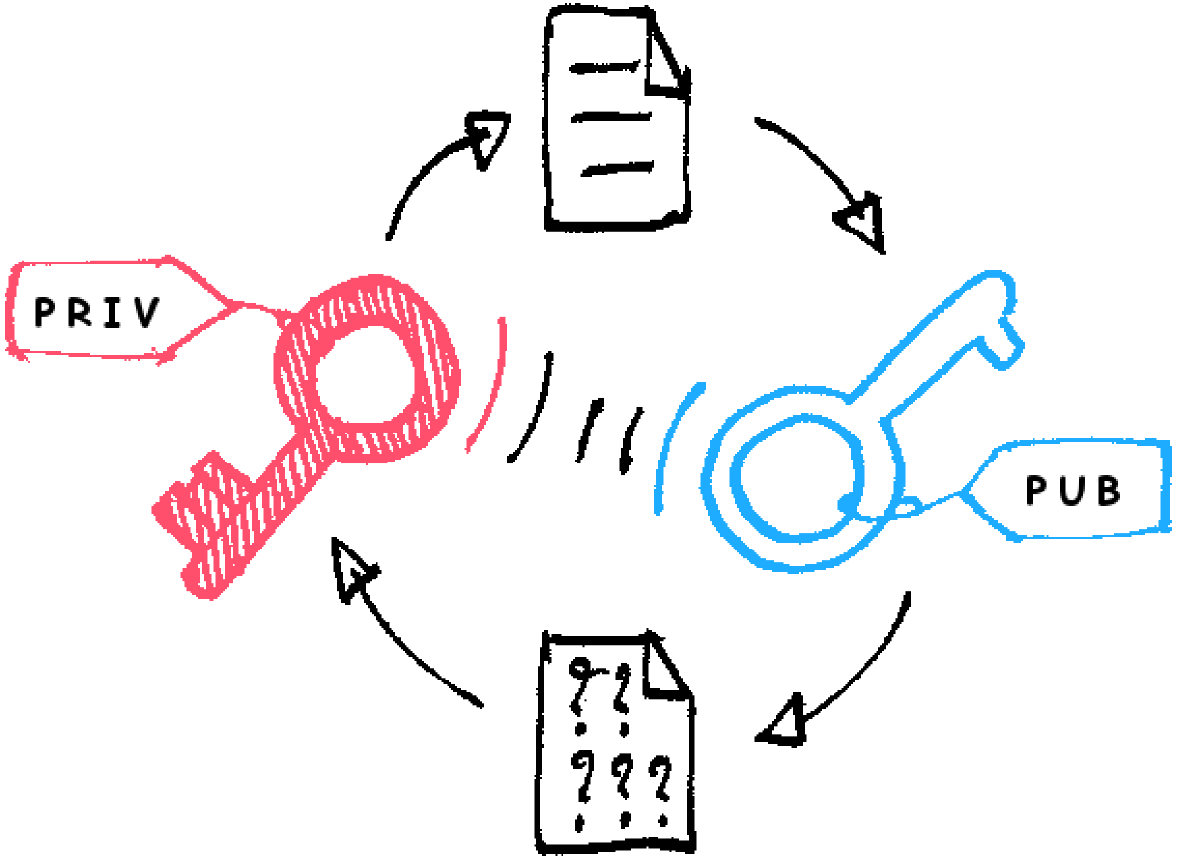


Picture from: https://www.youtube.com/watch?v=kEry1TaN4-k&index=13&list=WL&t=57s

How Does Quantum Computing Work

	Quantum computer	Parallel computer
1. Entanglement	Entanglement between qubits	Independent processor without entanglement
2. Measurement	One state after measurement	Measure any processors at any time
3. Computational power	**Exponentially** increase ($N = 2^n$)	**Linearly** increase

Possibilities of Quantum Computing: Cryptography



Picture from: https://en.wikipedia.org/wiki/Public-key_cryptography

Possibilities of Quantum Computing: Cryptography

Paralell computing → Large compute power

RSA Algorithm: large integer factorization

$$\left.\begin{array}{c} 1529 \div 3 = 509 \ldots\ldots 2 \\ 1529 \div 5 = 305 \ldots\ldots 4 \\ 1529 \div 7 = 218 \ldots\ldots 3 \\ 1529 \div 11 = 139 \end{array}\right\} \text{Shor's Algorithm}$$

150,000 years

300-bit large integer factorization

1 second

Picture from: https://en.wikipedia.org/wiki/Public-key_cryptography

Possibilities of Quantum Computing

Paralell computing → Large compute power

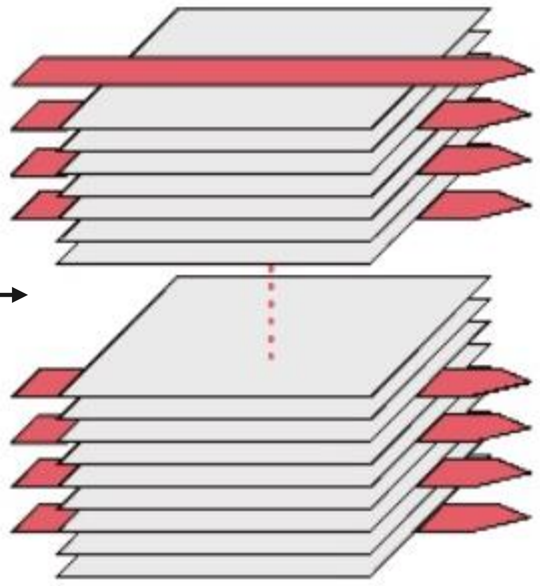
— Bit coins

— Database search: Grover's Alogrithm

— Quantum computing + Machine learning

— Quantum Fourier transform

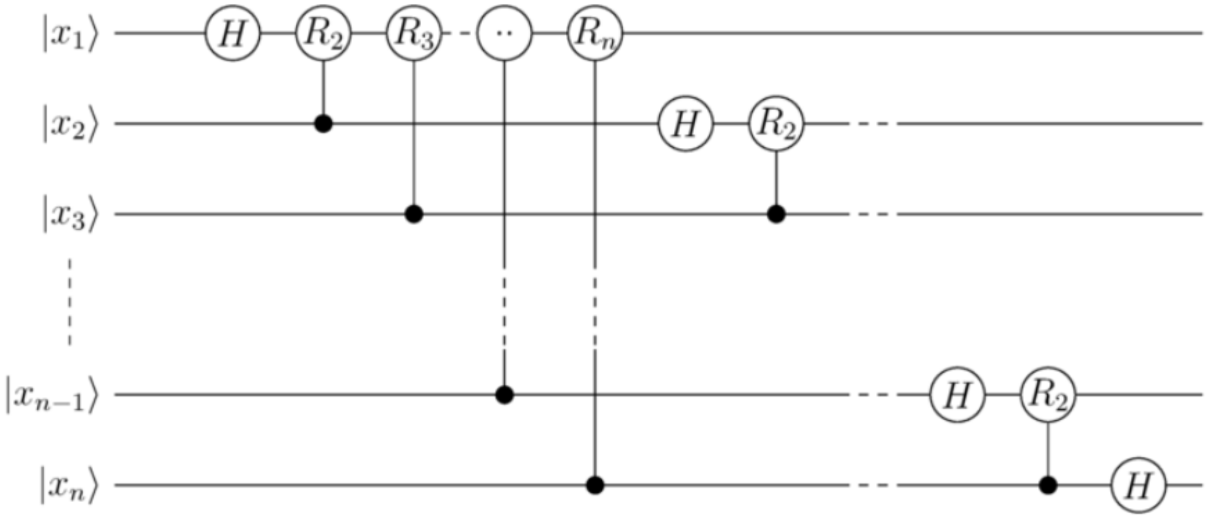
N-bit data →



$log_2 N$ qubit

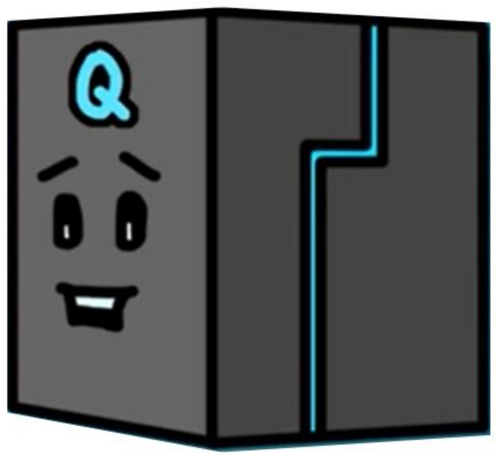
Picture from: https://zhuanlan.zhihu.com/p/27387032

Limitation of Quantum Computing



100 qubits → logical qubit (theoretical ideal)

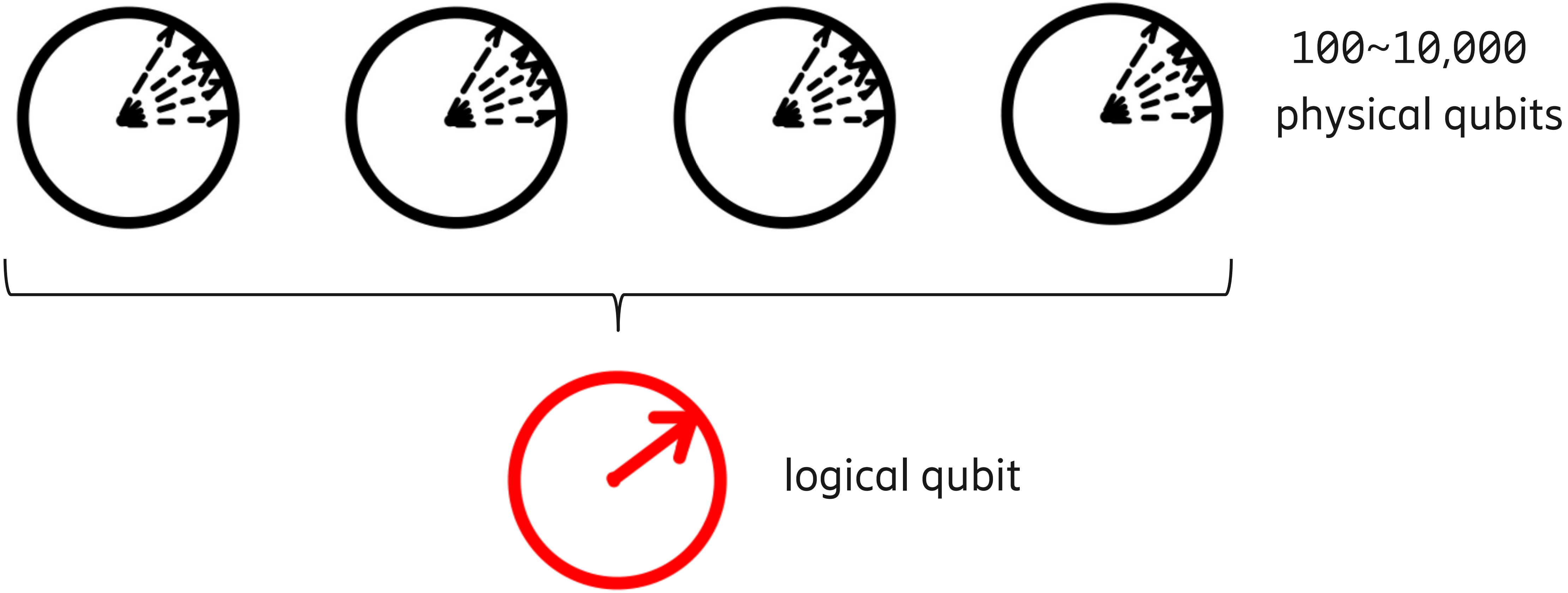
$\neq$



100 qubits → physical qubit (with noise)

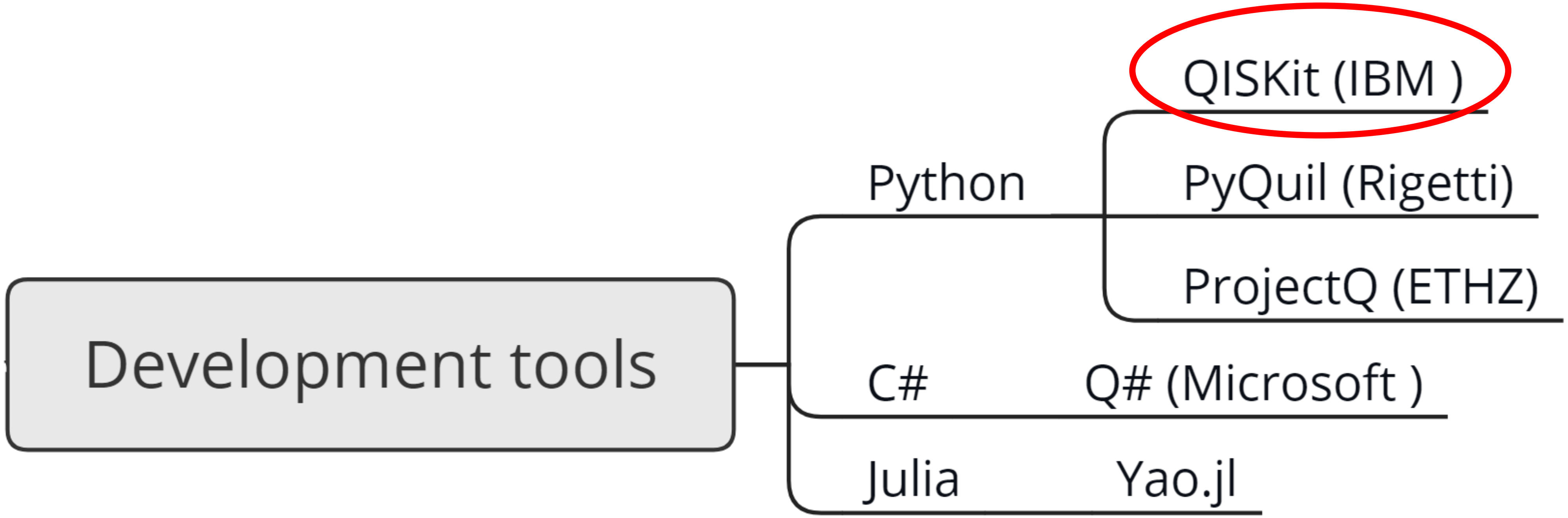
Picture from: https://www.youtube.com/watch?v=kEry1TaN4-k&index=13&list=WL&t=57s

Limitation of Quantum Computing



Quantum Error Correction

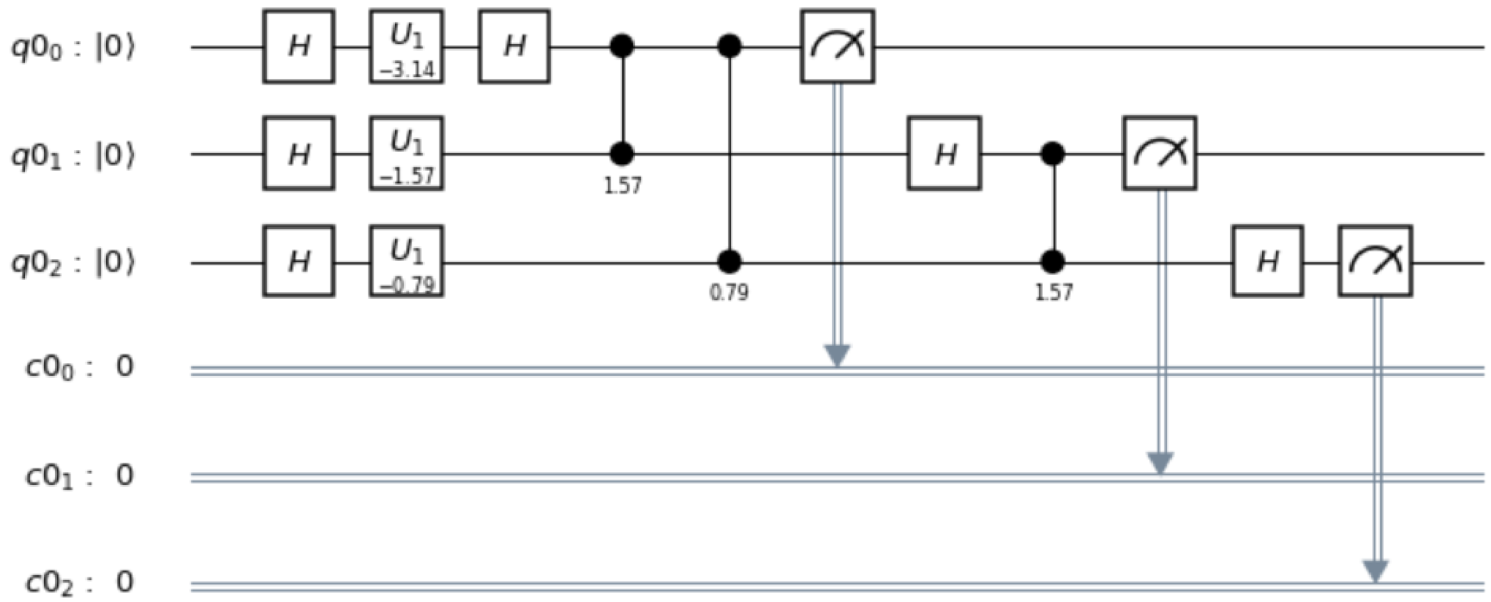
The Realization of Quantum Algorithms



The Realization of Quantum Algorithms

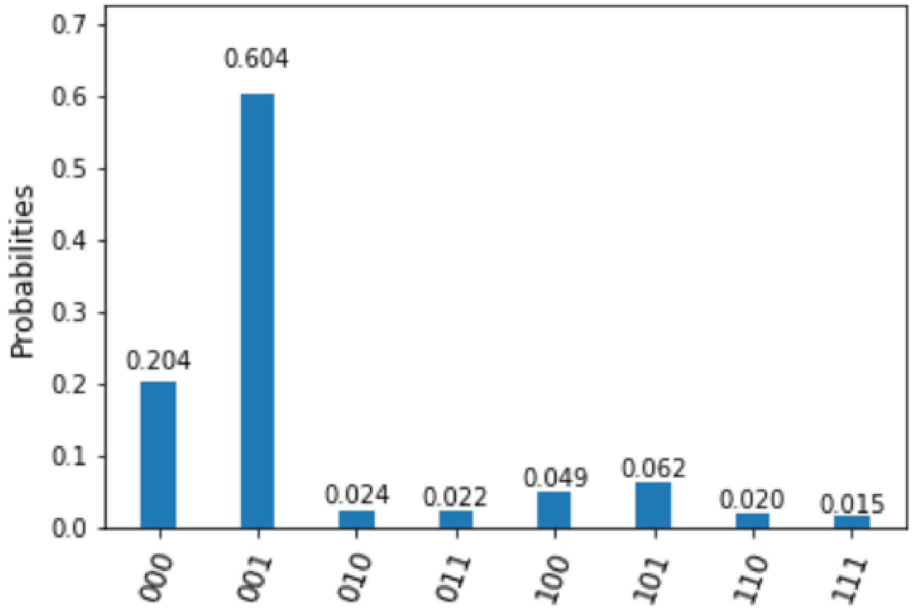
```
In [6]: # Visualizing quantum circuit
        from qiskit.tools.visualization import circuit_drawer
        circuit_drawer(qft_n)
```

```
WARNING: Unable to compile latex. Is `pdflatex` installed? Skipping latex circuit drawing...
```



The Realization of Quantum Algorithms

In [8]:
```
results = job_exp.result()
plot_histogram(results.get_counts())
```

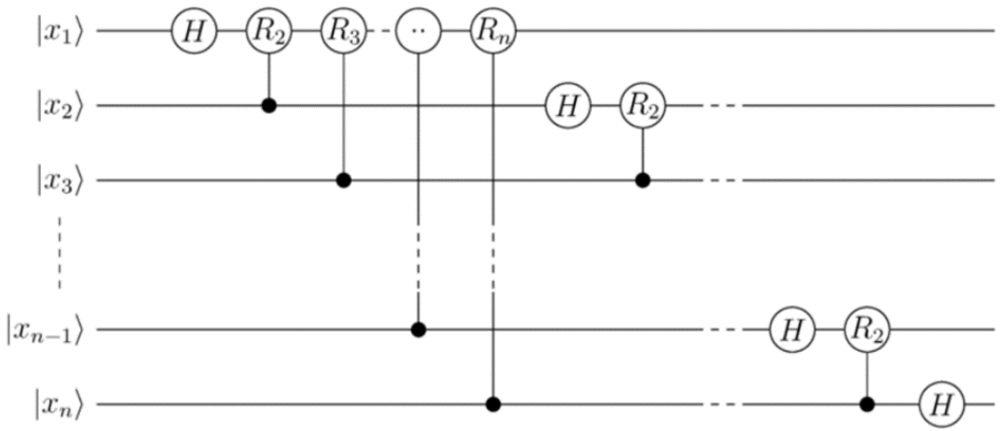


Matplotlib

The Realization of Quantum Fourier Transform

$$\underbrace{x_0, x_1, \ldots, x_{N-1}}_{\text{Length: N}} \Rightarrow \text{DFT: } y_k \equiv \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} x_j e^{2\pi i jk/N} \Rightarrow \underbrace{y_0, y_1, \ldots, y_{N-1}}_{\text{Length: N}}$$

$$\underbrace{|x_0, x_1, \ldots, x_{n-1}\rangle}_{\text{Length: n}} \Rightarrow$$



$$\Rightarrow \underbrace{|y_0, y_1, \ldots, y_{n-1}\rangle}_{\text{Length: n}}$$

$$N = 2^n$$

The Realization of Quantum Fourier Transform

$$\underbrace{x_0, x_1, \dots, x_{N-1}}_{\text{Length: N}} \Rightarrow \text{DFT: } y_k \equiv \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} x_j e^{2\pi i jk/N} \Rightarrow \underbrace{y_0, y_1, \dots, y_{N-1}}_{\text{Length: N}}$$

$$\underbrace{|x_0, x_1, \dots, x_{n-1}\rangle}_{\text{Length: n}} \Rightarrow \boxed{\text{N×N matrix}} \Rightarrow \underbrace{|y_0, y_1, \dots, y_{n-1}\rangle}_{\text{Length: n}}$$

$$N = 2^n$$

The Realization of Quantum Fourier Transform