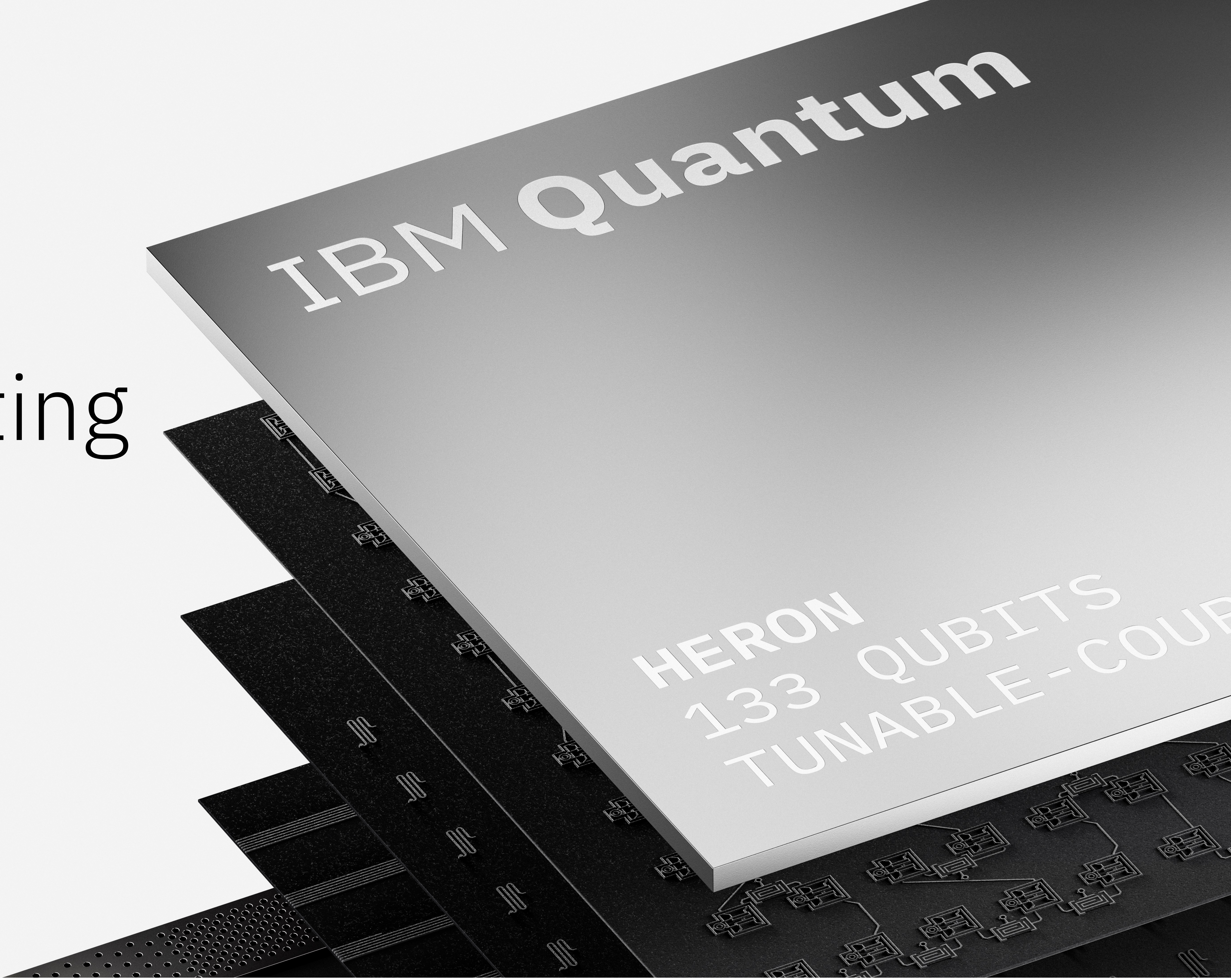
IBM Quantum

Introduction to Quantum Computing and Qiskit



Léna Pérennès
IBM Quantum Support Team
lena.perennes@ibm.com

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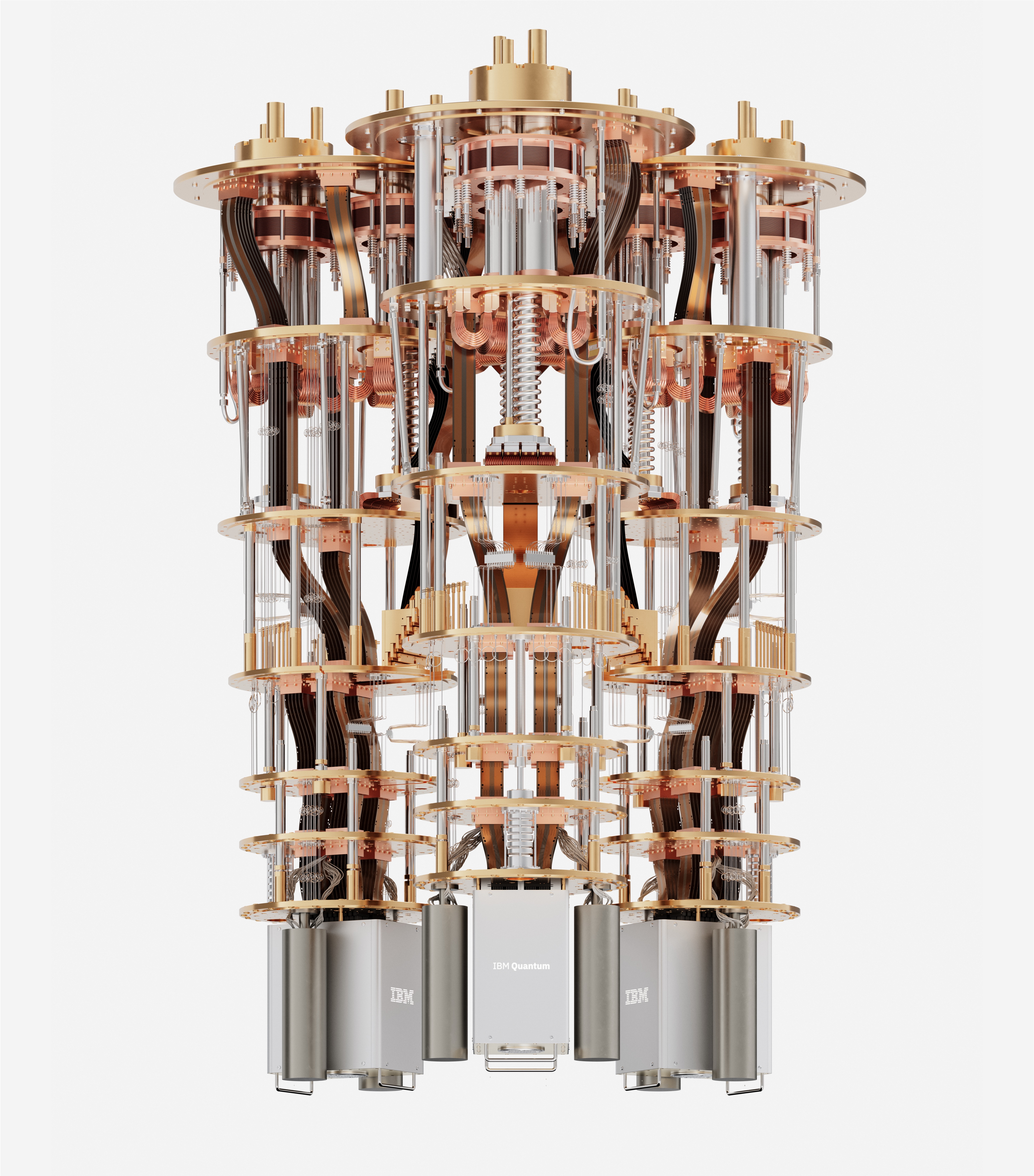
Introduction to Quantum Computing and Qiskit

- Introduction to quantum computing
- Getting started with the platform
- Introduction to qiskit
    - How to build, transpile, run a circuit
- How to look at your access with Qiskit
    - Instances and backends
    - List jobs or backends with filterings
- How to do basic troubleshooting with Qiskit
- Links to go further



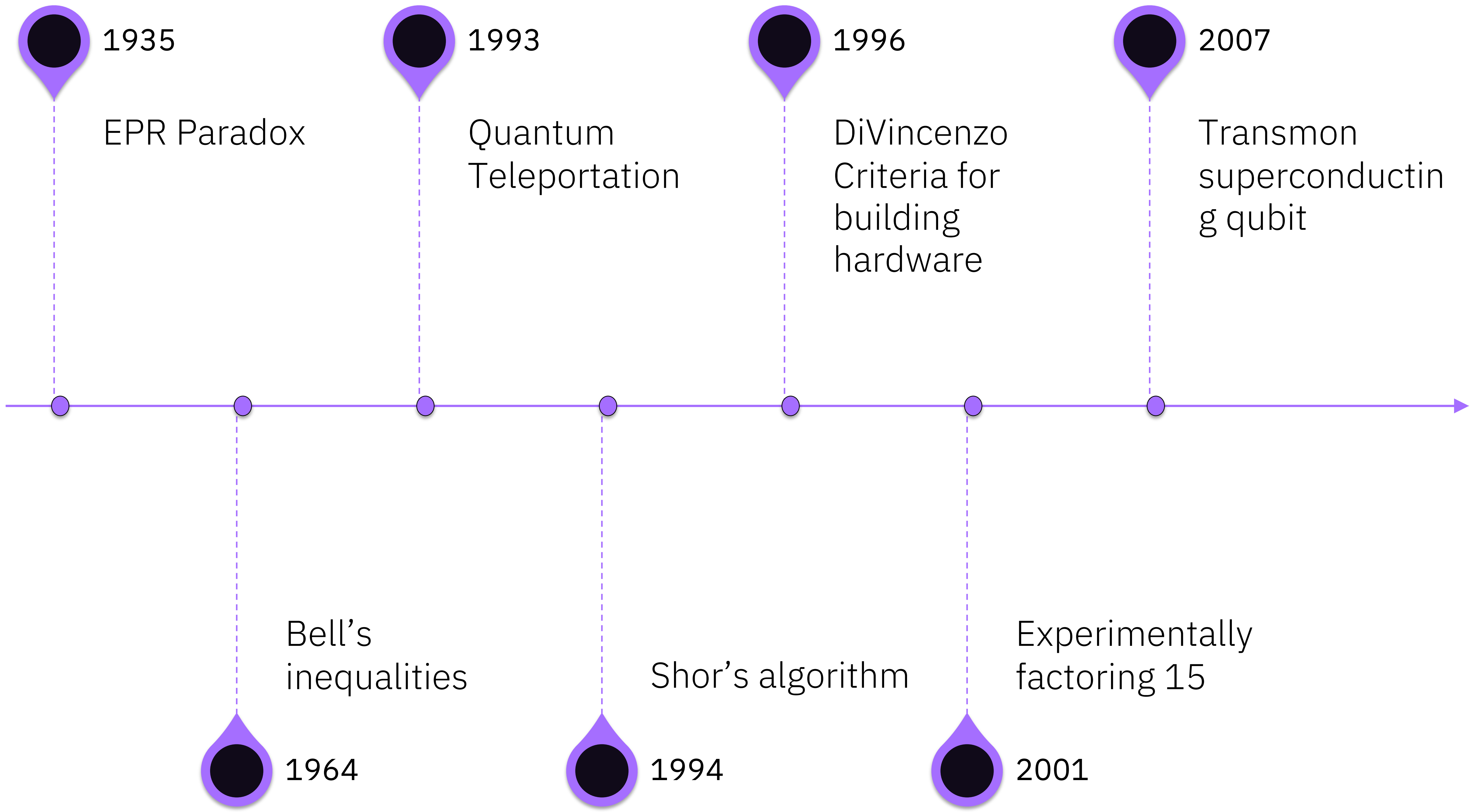
The limit of classical computation

“The underlying physical laws necessary for the mathematical theory of a large part of physics […] are ***completely known****, and the difficulty is only that the exact application of these laws leads to equations* ***much too complicated to be soluble****. It therefore becomes desirable that* ***approximate*** *practical methods […] should be developed…”*

Dirac 1929

“I’m not happy with all the analysis that go with just classical theory, because ***nature isn’t classical****, dammit. And if you want to make a* ***simulation of nature****, you’d better* ***make it quantum*** *mechanical, and, by golly, it’s a wonderful problem because it doesn’t look so easy”*

Feynman 1982

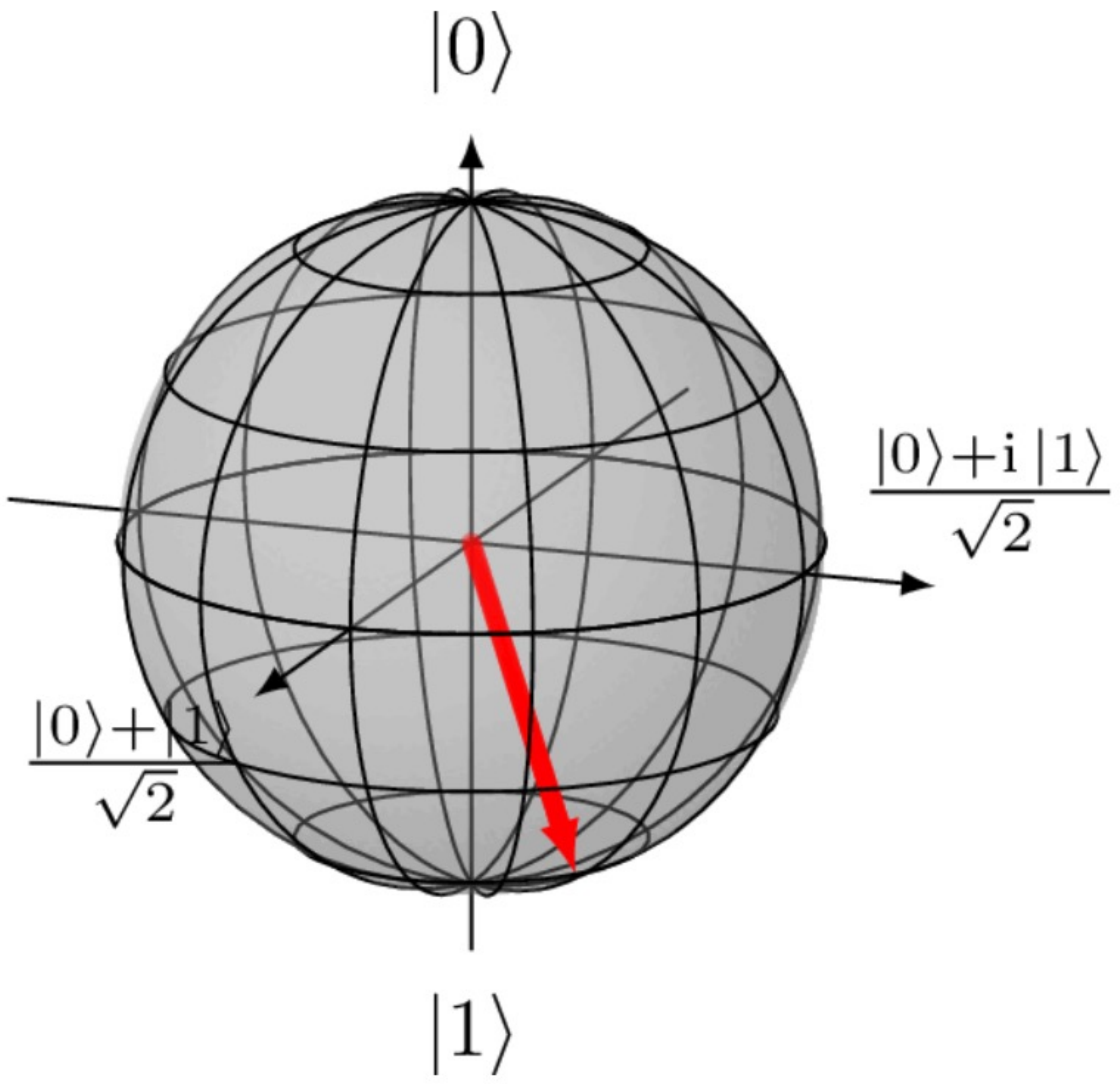


Introduction to quantum computing

When working with one bit, we can either have 1 or 0, nothing more, we're stuck in a discrete space.

A qubit, or a quantum bit, is a vector in the two-dimensional complex vector space $\mathbf{C}^2$ that can take any value within the space between 0 and 1. It is the unit of information we work on in quantum computing.

https://javafxpert.github.io/grok-bloch/

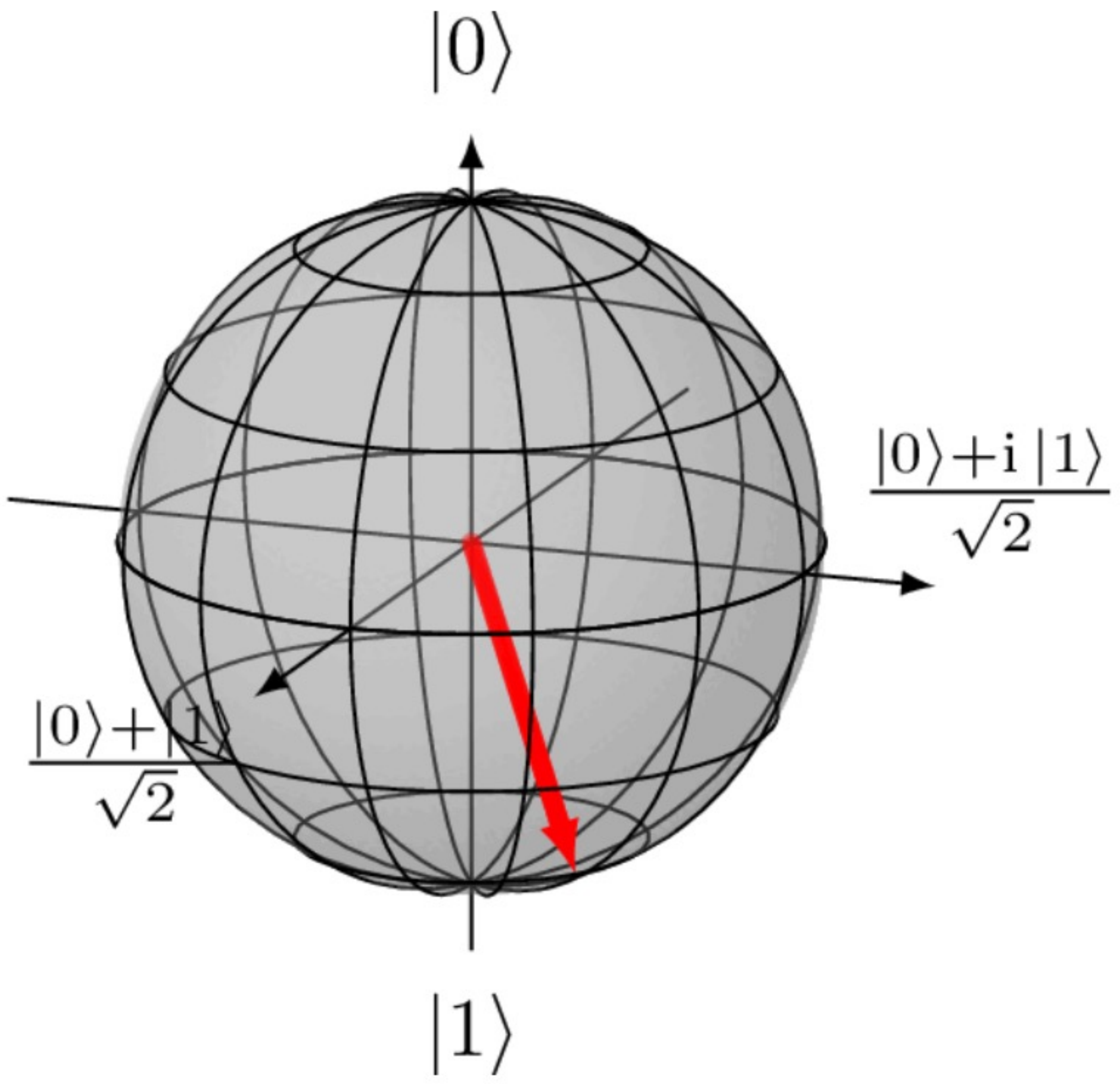


Introduction to quantum computing

A qubit, or a quantum bit, is a vector in the two-dimensional complex vector space $\mathbf{C}^2$ that can be written as a combination of $|0\rangle$ and $|1\rangle$:

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad \text{and} \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$|0\rangle$ and $|1\rangle$ are called *ket zero* and *ket one*. These two vectors form what we call the **computational basis** for the one-qubit space.



Introduction to quantum computing

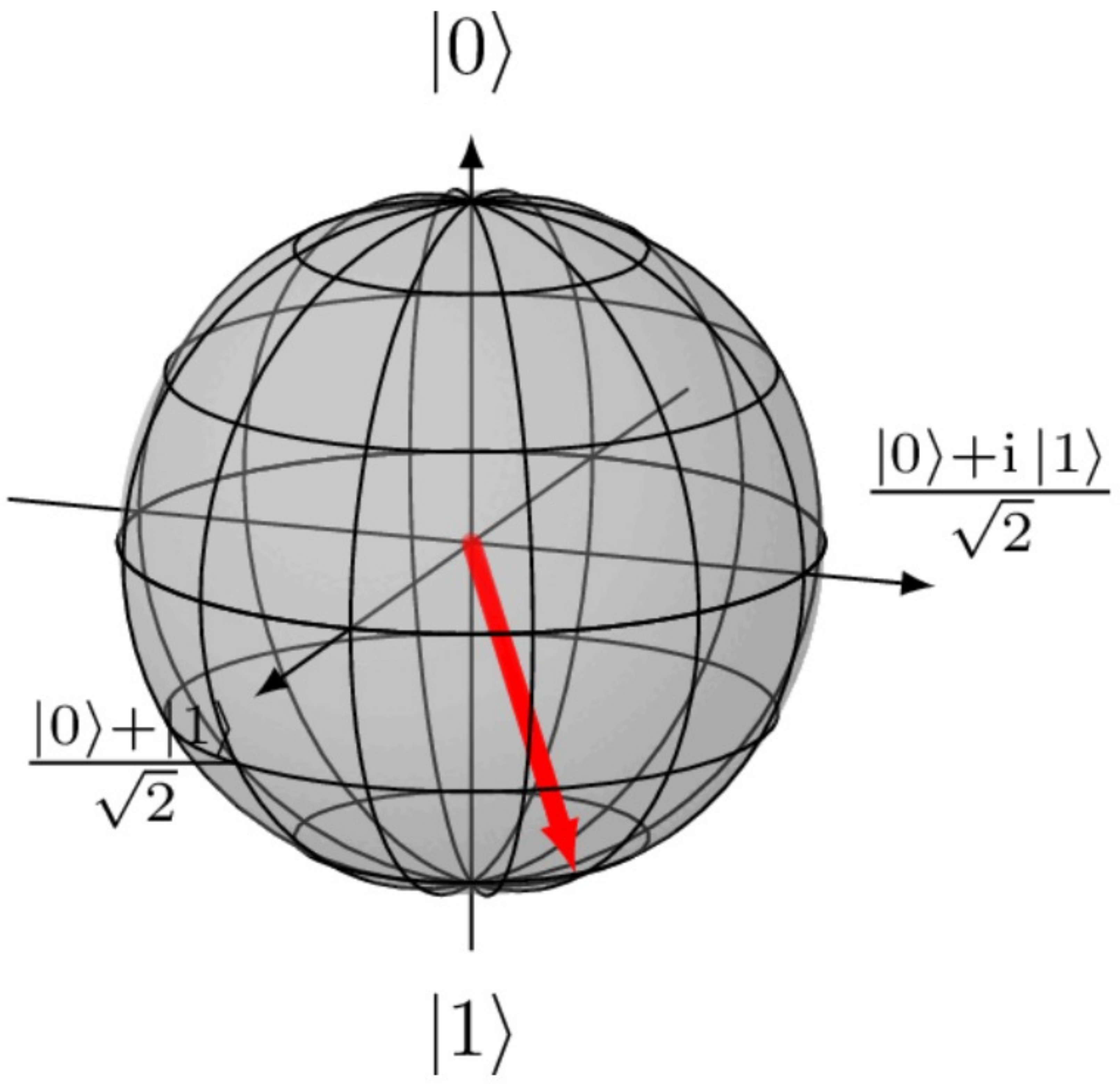
Any qubit can be written as a superposition of $|0\rangle$ and $|1\rangle$:

$$a\,|0\rangle + b\,|1\rangle = \begin{bmatrix} a \\ b \end{bmatrix}$$

Where a and b are complex numbers called **amplitudes** and verify

$$|a|^2 + |b|^2 = 1$$

The **normalization** constraint comes from the fact that we work with probability amplitudes.



Introduction to quantum computing

It is possible to generalize these notations to several qubits. For 2 qubits, the computational basis will be

$$|00\rangle = |0\rangle \otimes |0\rangle = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \qquad |01\rangle = |0\rangle \otimes |1\rangle = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

$$|10\rangle = |1\rangle \otimes |0\rangle = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}, \qquad |11\rangle = |1\rangle \otimes |1\rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

Introduction to quantum computing

Any 2-qubit state can be written as a combination of the 4 qubits :

$$a\,|00\rangle + b\,|01\rangle + c\,|10\rangle + d\,|11\rangle$$

where *a, b, c,* and *d* are complex numbers called amplitudes and verify

$$|a|^2 + |b|^2 + |c|^2 + |d|^2 = 1$$

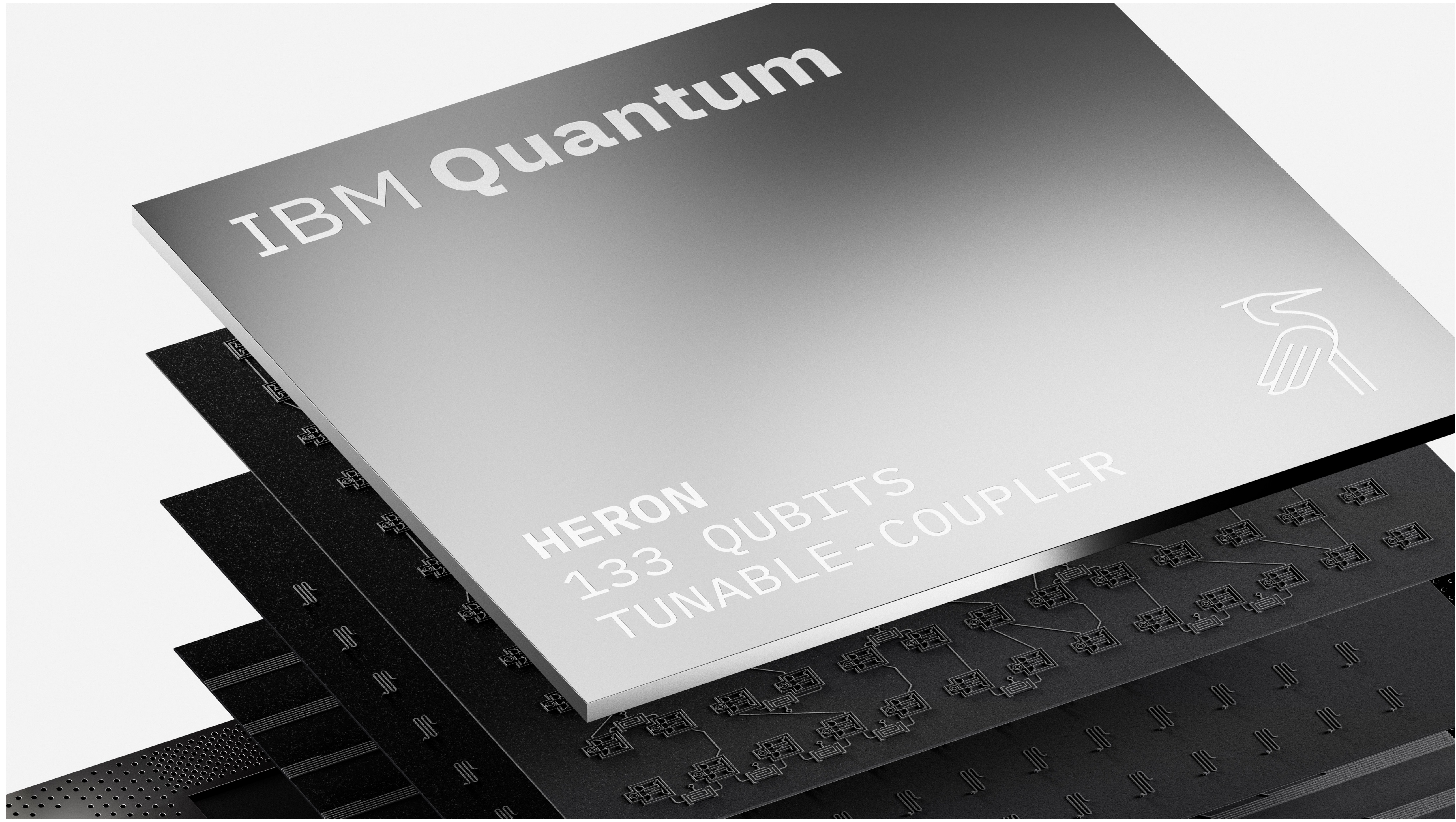
For n qubits, all possible bitstring will form the computational basis (2^n elements) and every n-qubit state can be written as a superposition of the basis states. We're working in a 2^n dimensional space, its growth is exponential.

Introduction to quantum computing

All information and results of a qubit are not directly available to us, we need to measure the state. It will force the qubit to collapse to $|0\rangle$ or $|1\rangle$ by observing it, where

- $|a|^2$ is the probability we will get $|0\rangle$ when we measure
- $|b|^2$ is the probability we will get $|1\rangle$ when we measure

Repeated measurement is needed to approximate the statistical distribution of the qubit.



Introduction to quantum computing

When working with a multi-qubits state, **entanglement** describes the fact that qubits can't be separated.

For example, we can write

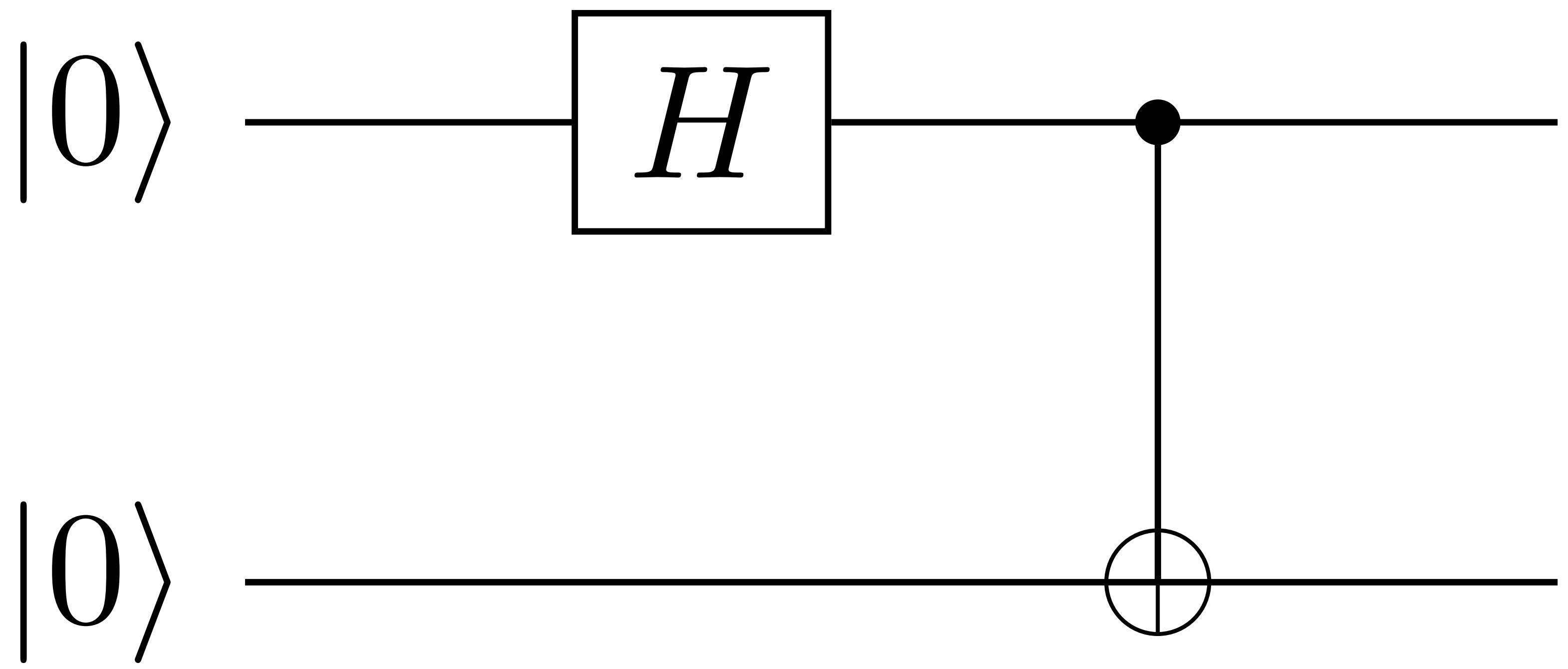
$$\frac{1}{\sqrt{2}}(|00\rangle + |01\rangle) = \frac{1}{\sqrt{2}}|0\rangle \otimes (|0\rangle + |1\rangle)$$

but we cannot write

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \neq |\alpha\rangle \otimes |\beta\rangle$$

as the "product" of two single qubit states.

Once you measure the first qubit,
the second is uniquely determined.

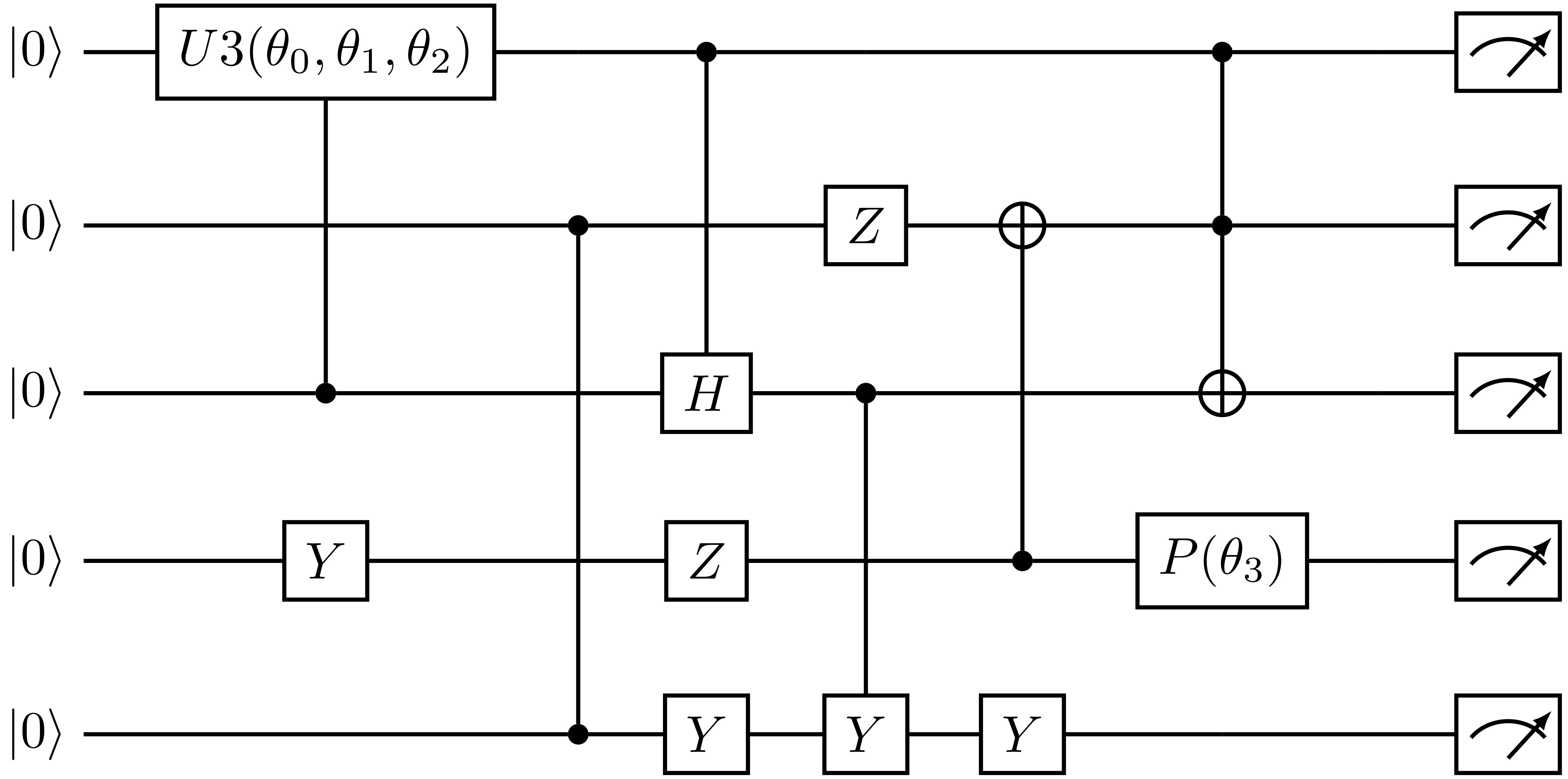


$$\rightarrow \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

Introduction to quantum computing

Similarly to classical gates such as AND or NOT, the quantum state will evolve through quantum gates. Based on the normalization constraint of a quantum state, a gate will be unitary, and therefore reversible.

A quantum circuit is a set of quantum gates that we will apply to the quantum state. A quantum algorithm will use a quantum circuit as a routine.



Introduction to quantum computing

The Pauli gates are a set of 1-qubit operations that play a groudn role in quantum computing. Each gate represent a rotation of 180 degres over the respectives axis of the Bloch sphere.

X is known as the NOT gate, or bit flip.

Z is known as the phase flip.

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \begin{cases} X|0\rangle = |1\rangle \\ X|1\rangle = |0\rangle \end{cases}$$

$$Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \begin{cases} Y|0\rangle = i|1\rangle \\ Y|1\rangle = -i|0\rangle \end{cases}$$

$$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \begin{cases} Z|0\rangle = |0\rangle \\ Z|1\rangle = -|1\rangle \end{cases}$$

Introduction to quantum computing

The Hadamard gate is a 1-qubit operation that maps the two qubits states into an equal superposition between them.

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

The square of the Hadamard gate is equal to the identity : applying twice the gate is equivalent to doing nothing.

$$\begin{cases} H|0\rangle = \dfrac{|0\rangle + |1\rangle}{\sqrt{2}} = |+\rangle \\ H|1\rangle = \dfrac{|0\rangle - |1\rangle}{\sqrt{2}} = |-\rangle \end{cases}$$

Introduction to quantum computing

The CX gate, or CNOT gate, is a 2-qubit operation that applies the X gate on the qubit target depending on the value of the control target. If the control is equal to 1, then the target qubit flips.

$$\text{CX} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}, \begin{cases} CX|00\rangle = |00\rangle \\ CX|01\rangle = |01\rangle \\ CX|10\rangle = |11\rangle \\ CX|11\rangle = |10\rangle \end{cases}$$

Introduction to quantum computing

We inherit some rules from quantum mechanics :

➔ No-cloning theorem : we cannot copy any arbitrary state $|\psi\rangle = a\,|0\rangle + b\,|1\rangle$ into another arbitrary state.

- ➔ In order to copy a state, you would have to access its information ➔ collapsing through the measure
- ➔ Get the information by applying controlled gates on qubits ➔ we introduce entanglement and qubits are not independent anymore

➔ No-deleting theorem : we saw gates are unitary so reversible, being able to delete a state would be in contradiction with it.