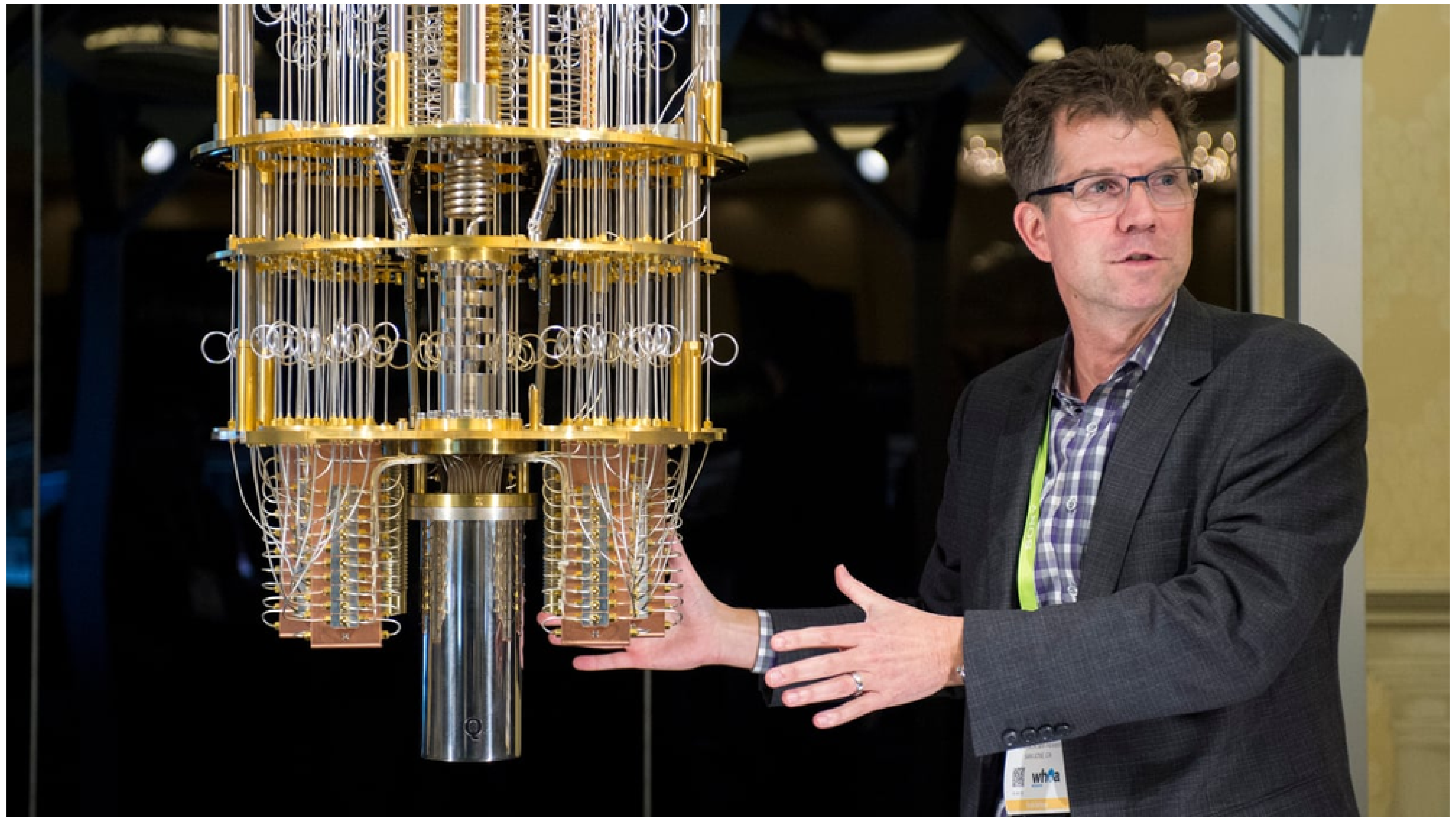
Intro to Quantum ML with Python

Artificial Intelligence Association of Thailand (AIAT)

ปิติกร คล้ายสำเนียง

Quantum Computer

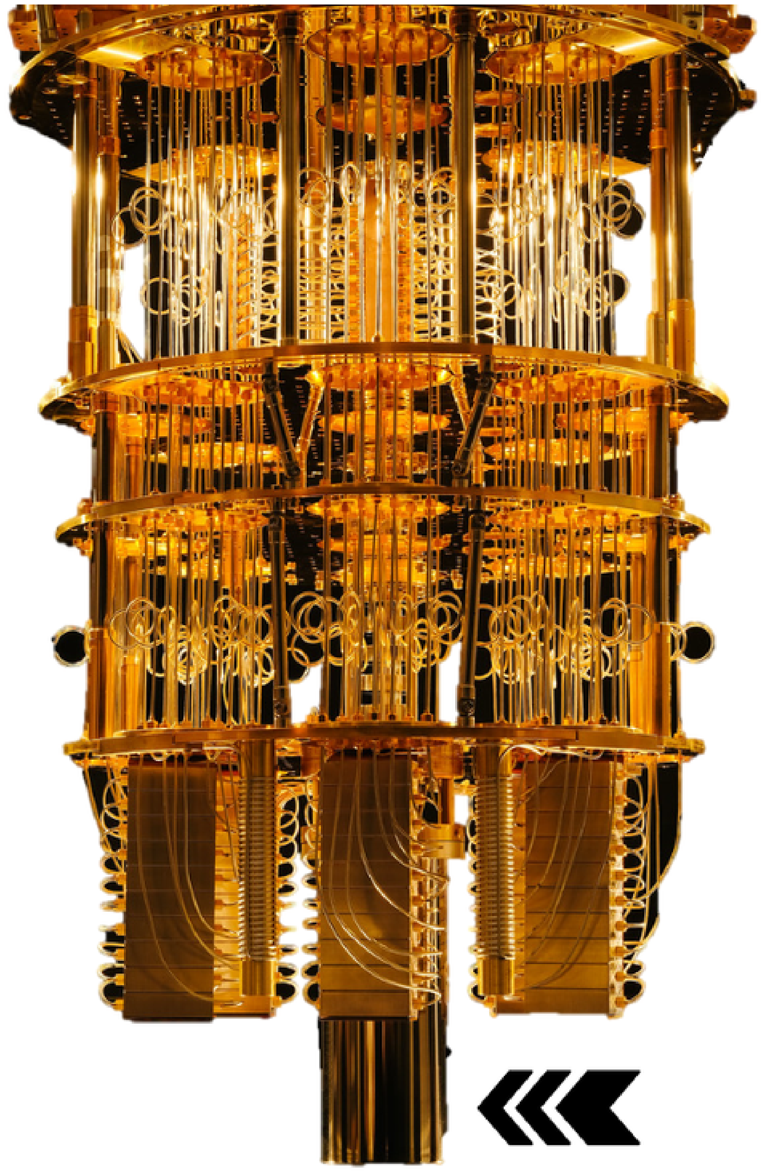
A Quantum Computer is a type of computing device that leverages the principles of quantum mechanics to perform calculations and solve problems in ways that classical computers cannot.

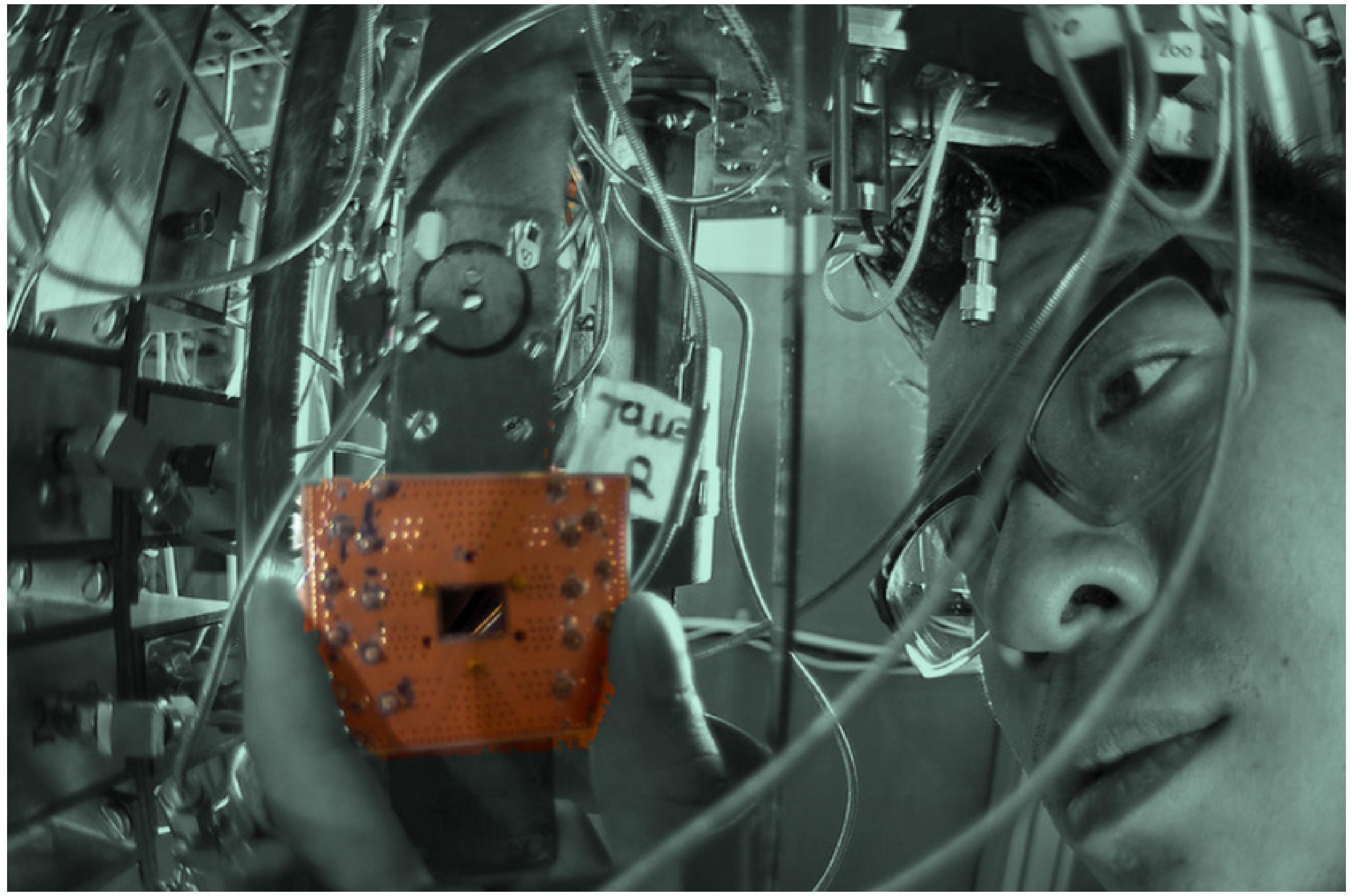


IBM Raises the Bar with a 50-Qubit Quantum Computer

Quantum Computer

An IBM Q cryostat used to keep IBM’s 50-qubit quantum computer cold in the IBM Q lab in Yorktown Heights, New York.





IBM Raises the Bar with a 50-Qubit Quantum Computer

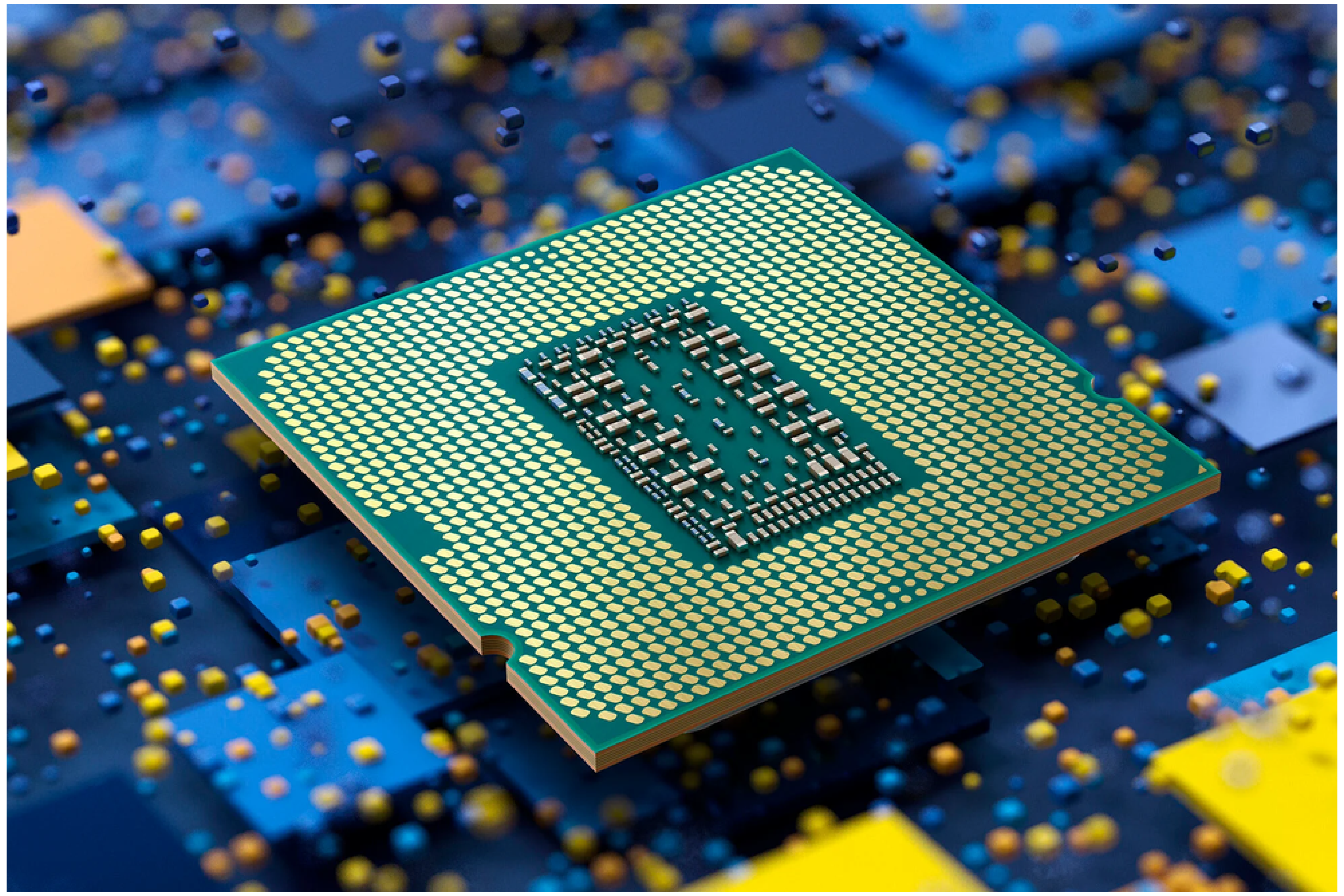
Quantum Computer

Key Concepts

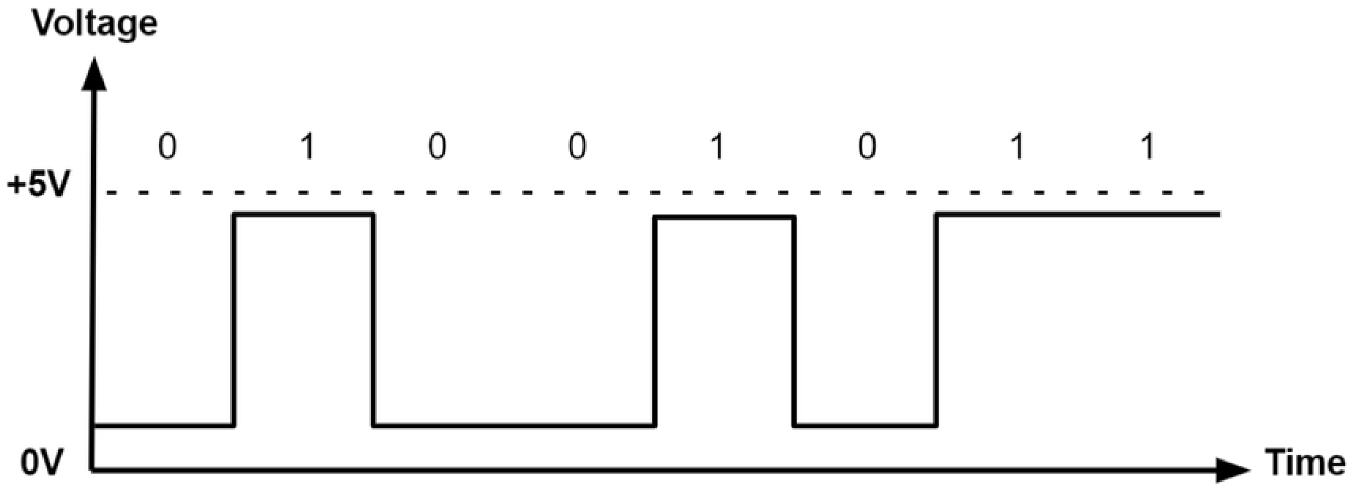
- Superposition: Qubits can be in a superposition of states, meaning they can represent a combination of 0 and 1 simultaneously. For example, a qubit can exist as $\alpha|0\rangle + \beta|1\rangle$, where α and β are complex numbers (probability amplitudes) that determine the probability of measuring 0 or 1 upon observation.

- Entanglement: Quantum computers can create and manipulate entangled qubits. When qubits are entangled, the state of one qubit is instantly correlated with the state of another, regardless of the distance between them.

Classical Computing

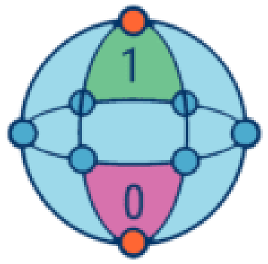
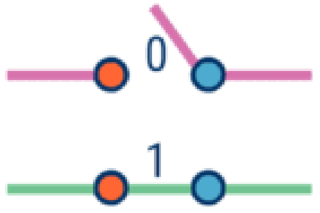
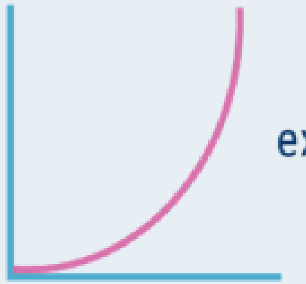
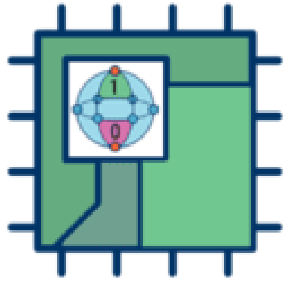
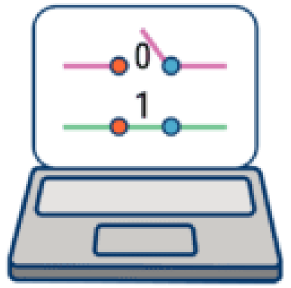
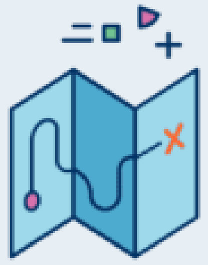


state can either be “0” or “1”



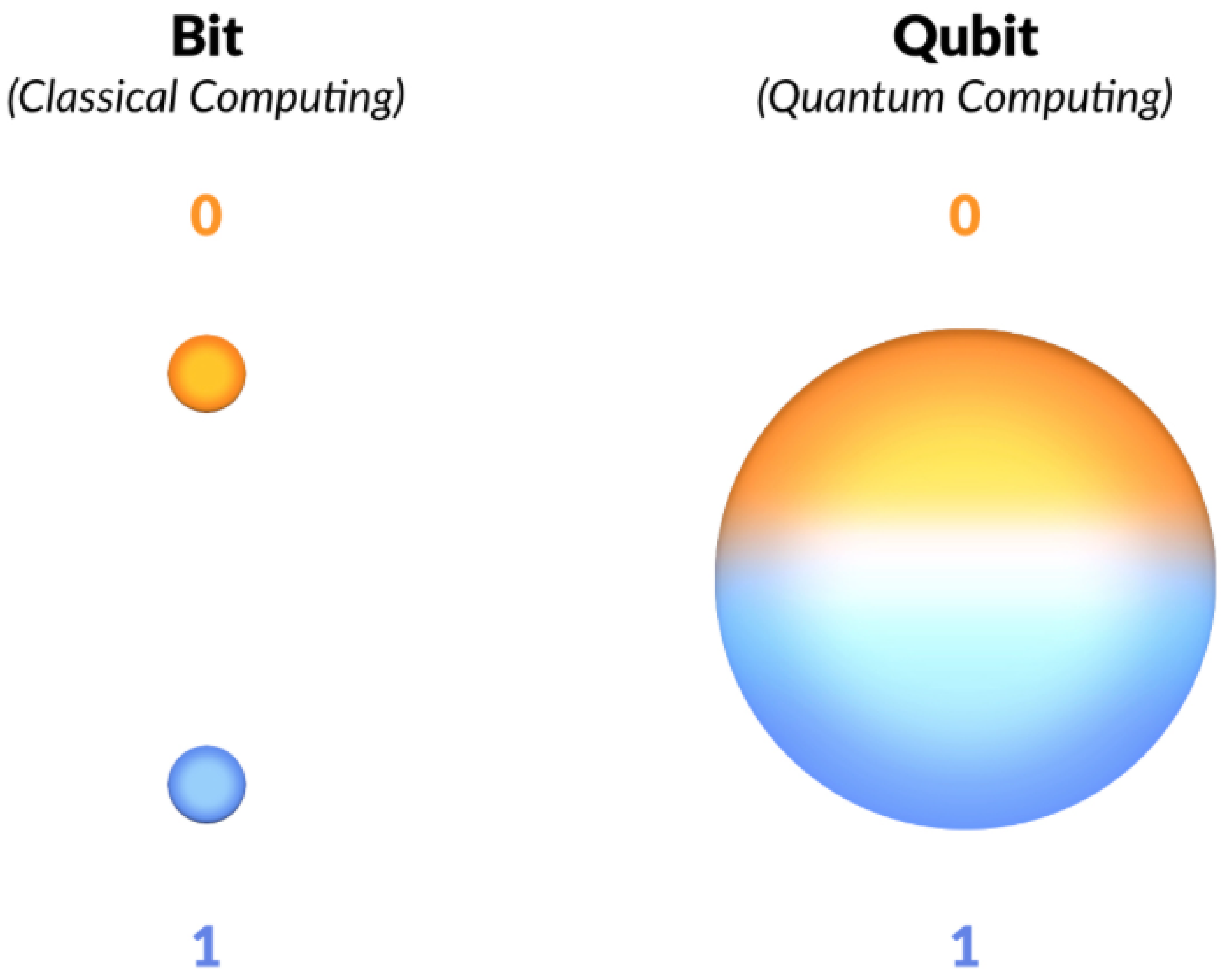
1 0

Quantum Computing Vs. Classical Computing

Quantum Computing	Classical Computing
 Calculates with qubits, which can represent 0 and 1 at the same time	Calculates with transistors, which can represent either 0 or 1 
 Power increases exponentially in proportion to the number of qubits	Power increases in a 1:1 relationship with the number of transistors 
 Quantum computers have high error rates and need to be kept ultracold	Classical computers have low error rates and can operate at room temp 
 Well suited for tasks like optimization problems, data analysis, and simulations	Most everyday processing is best handled by classical computers 

Qubit

Quantum computers use qubits as the basic unit of information. Unlike classical bits that represent 0 or 1, qubits can exist in multiple states simultaneously due to the principles of superposition. This allows quantum computers to process vast amounts of information in parallel.



Qubit

Complex numbers

$$|\Psi(a,b)\rangle = a|0\rangle + \mathrm{b}|1\rangle$$

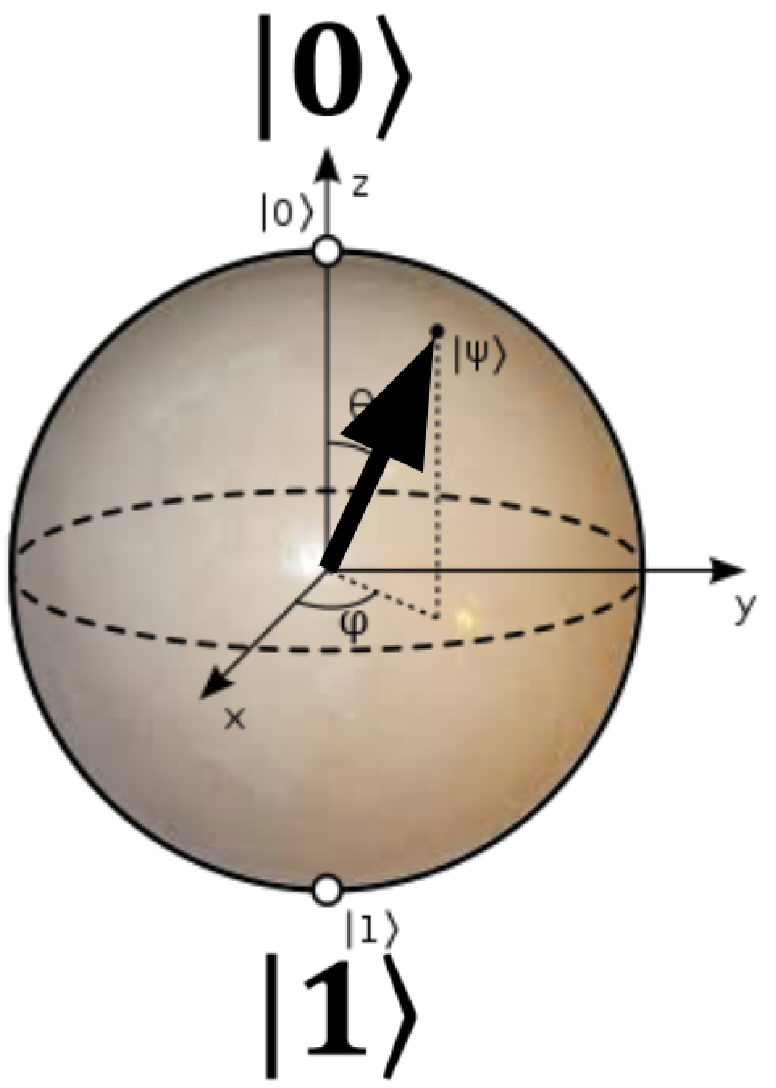
$$= |a|e^{i\phi_a}|0\rangle + |\mathrm{b}|e^{i\phi_b}|1\rangle$$

$$= e^{i\phi_a}(|a||0\rangle + |\mathrm{b}|e^{i(\phi_b-\phi_a)}|1\rangle)$$

$$= |a||0\rangle + |\mathrm{b}|e^{i\varphi}|1\rangle)$$

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

$$|\Psi(\theta,\varphi)\rangle = \cos(\frac{\theta}{2})|0\rangle + \sin(\frac{\theta}{2})e^{i\varphi}|1\rangle$$



Qubit

"every point" on the sphere is a valid state

Qubit (Examples)

$$|\Psi(\theta,\varphi)\rangle = \cos(\frac{\theta}{2})|0\rangle + \sin(\frac{\theta}{2})e^{i\varphi}|1\rangle$$

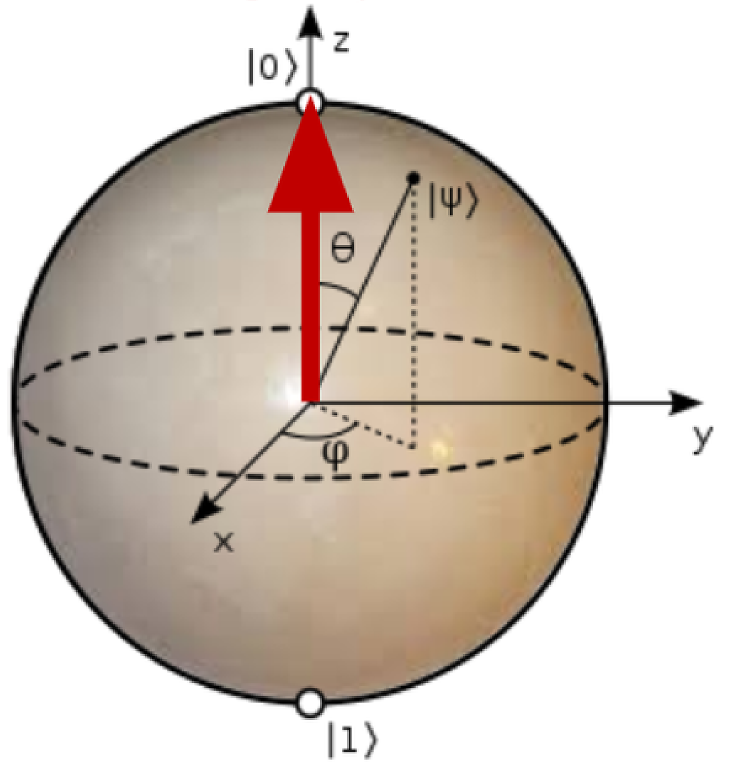
$$|\Psi(\theta = 0, \varphi = 0)\rangle = ?$$

$$= \cos(\frac{0}{2})|0\rangle + \sin(\frac{0}{2})e^{i0}|1\rangle$$

$$= 1|0\rangle + (0)(1)\,|1\rangle)$$

$$= |0\rangle$$

$|0\rangle$



Qubit (Examples)

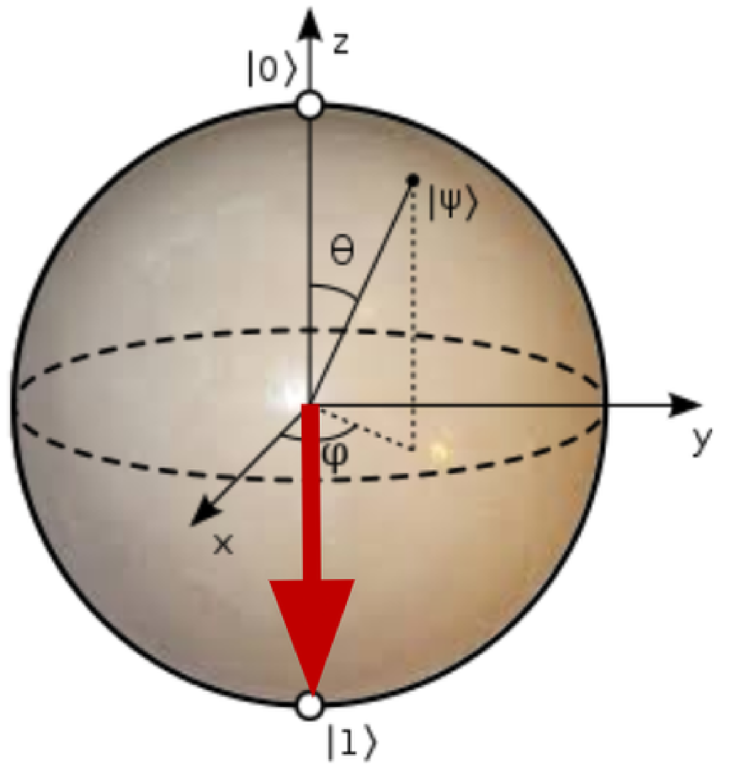
$$|\Psi(\theta,\varphi)\rangle = \cos(\frac{\theta}{2})|0\rangle + \sin(\frac{\theta}{2})e^{i\varphi}|1\rangle$$

$$|\Psi(\theta=\pi,\varphi=0)\rangle = ?$$

$$= \cos(\frac{\pi}{2})|0\rangle + \sin(\frac{\pi}{2})e^{i0}|1\rangle$$

$$= (0)|0\rangle + (1)(1)\ |1\rangle)$$

$$= |1\rangle$$



$|1\rangle$

Qubit (Examples)

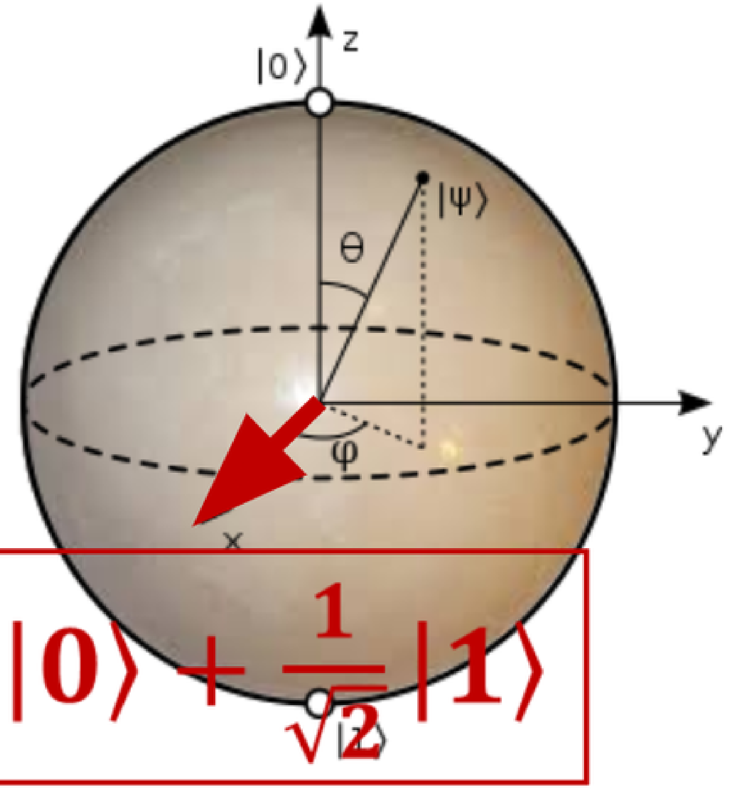
$$|\Psi(\theta,\varphi)\rangle = \cos\left(\frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|1\rangle$$

$$|\Psi(\theta = \pi/2, \varphi = 0)\rangle = ?$$

$$= \cos\left(\frac{\pi}{4}\right)|0\rangle + \sin\left(\frac{\pi}{4}\right)e^{i0}|1\rangle$$

$$= \left(\frac{1}{\sqrt{2}}\right)|0\rangle + \left(\frac{1}{\sqrt{2}}\right)(1)\ |1\rangle$$

$$= \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$



$$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

Qubit (Examples)

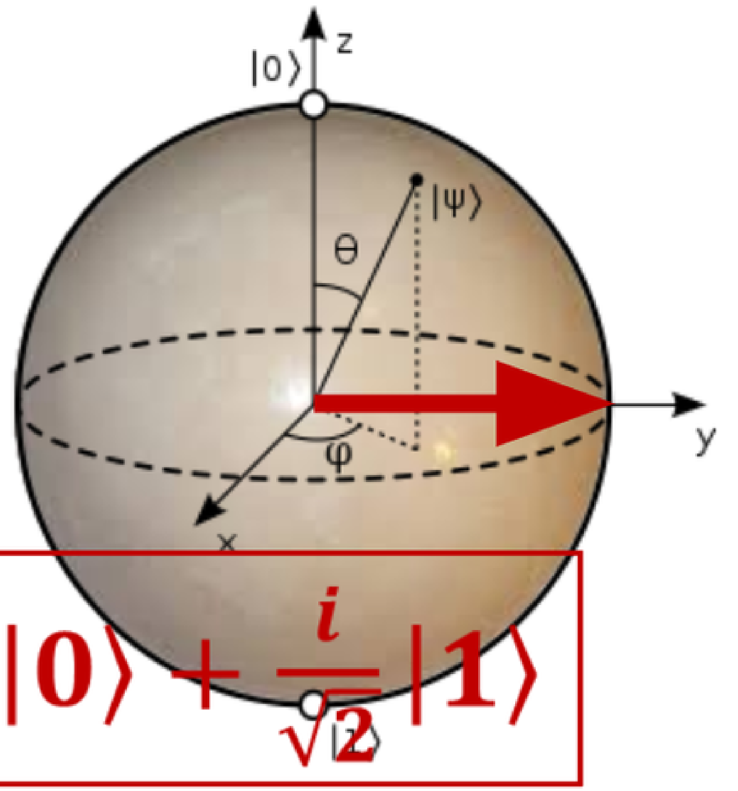
$$|\Psi(\theta,\varphi)\rangle = \cos(\tfrac{\theta}{2})|0\rangle + \sin(\tfrac{\theta}{2})e^{i\varphi}|1\rangle$$

$$|\Psi(\theta=\pi/2, \varphi=\pi/2)\rangle = ?$$

$$= \cos(\tfrac{\pi}{4})|0\rangle + \sin(\tfrac{\pi}{4})e^{i\frac{\pi}{2}}|1\rangle$$

$$= (\tfrac{1}{\sqrt{2}})|0\rangle + (\tfrac{1}{\sqrt{2}})(i)\,|1\rangle$$

$$= \frac{1}{\sqrt{2}}|0\rangle + \frac{i}{\sqrt{2}}|1\rangle$$



$$\frac{1}{\sqrt{2}}|0\rangle + \frac{i}{\sqrt{2}}|1\rangle$$

Qubit (Matrix representation)

$$|\Psi\rangle = a|0\rangle + b|1\rangle \quad \Longleftrightarrow \quad |\Psi\rangle = \begin{bmatrix} a \\ b \end{bmatrix}$$

Complex numbers

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

Qubit (Matrix representation)

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

$|0\rangle \Longleftrightarrow \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle \Longleftrightarrow \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ 1 \end{bmatrix}$

$|1\rangle \Longleftrightarrow \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

$\frac{1}{\sqrt{2}}|0\rangle + \frac{i}{\sqrt{2}}|1\rangle \Longleftrightarrow \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ i \end{bmatrix}$

Representation of Qubit

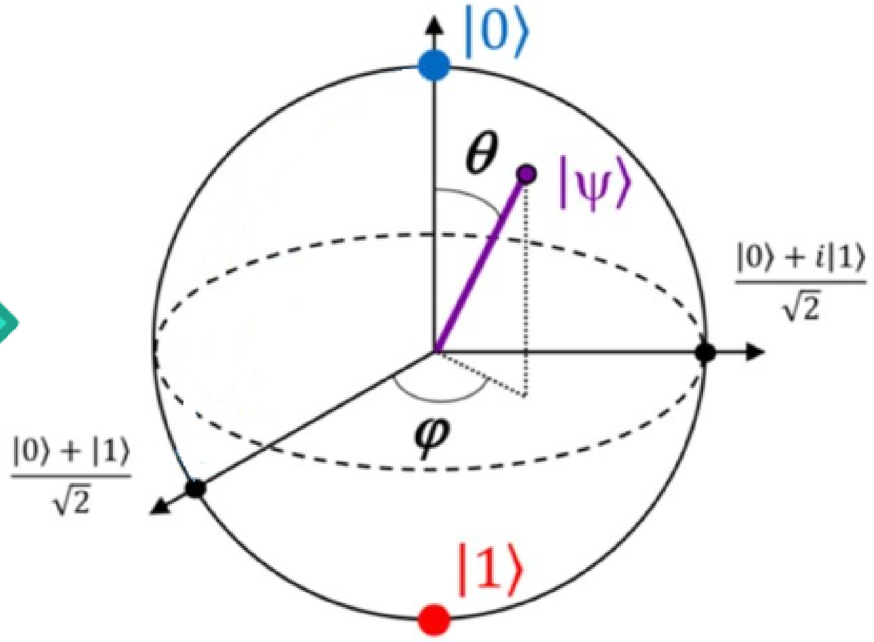
- **ket**

$$\boxed{|\Psi\rangle = a|0\rangle + b|1\rangle}$$

Complex numbers

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

- **Bloch sphere**



$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\varphi}\sin\frac{\theta}{2}|1\rangle$$

- **Matrix**

$$|\Psi\rangle = \begin{bmatrix} a \\ b \end{bmatrix}$$

1-Qubit Gate

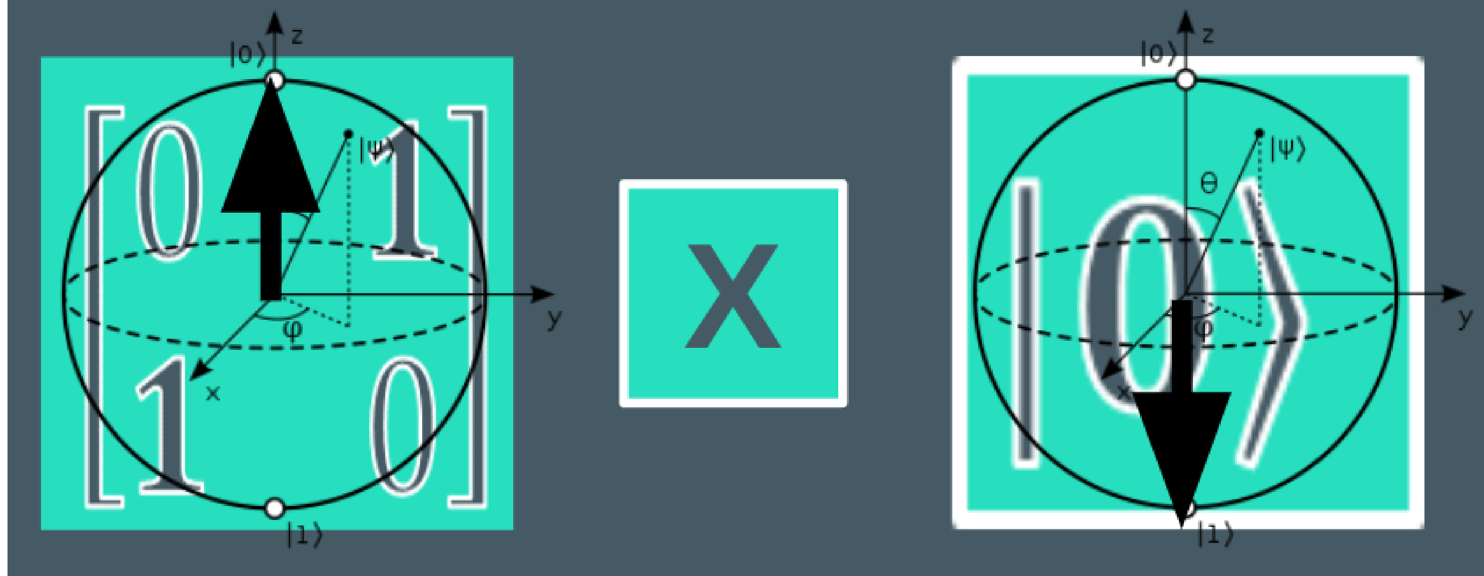
(Pauli) X Gate,

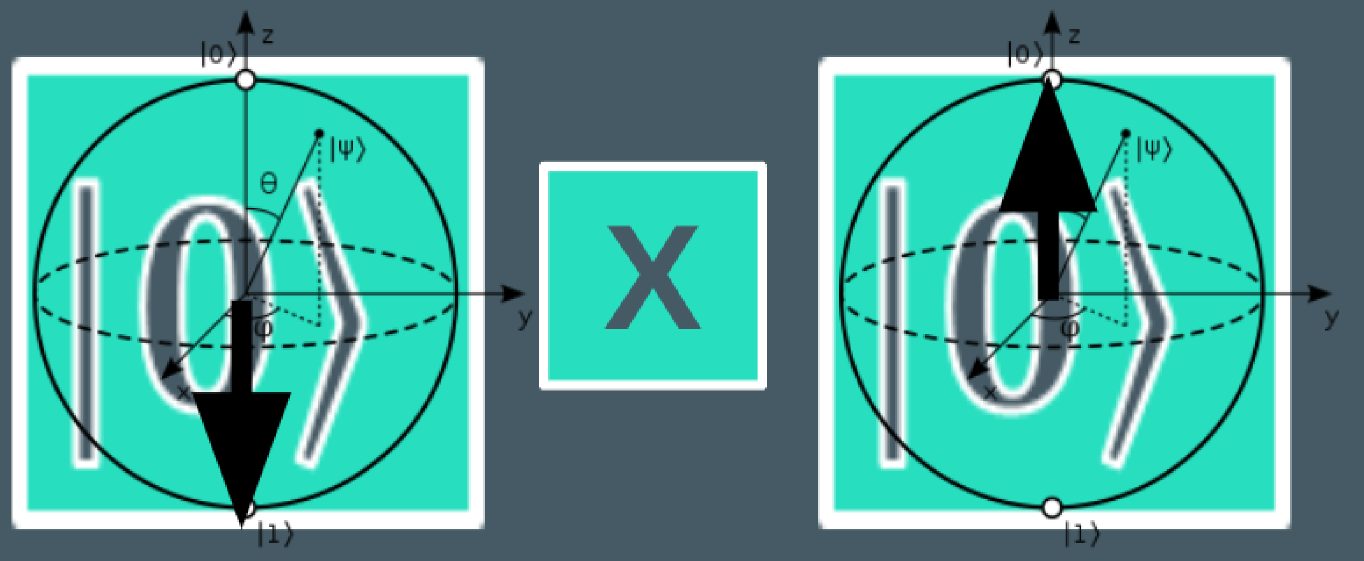
—[X]—

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

$|0\rangle$ — X — $|1\rangle$

$|1\rangle$ — X — $|0\rangle$





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

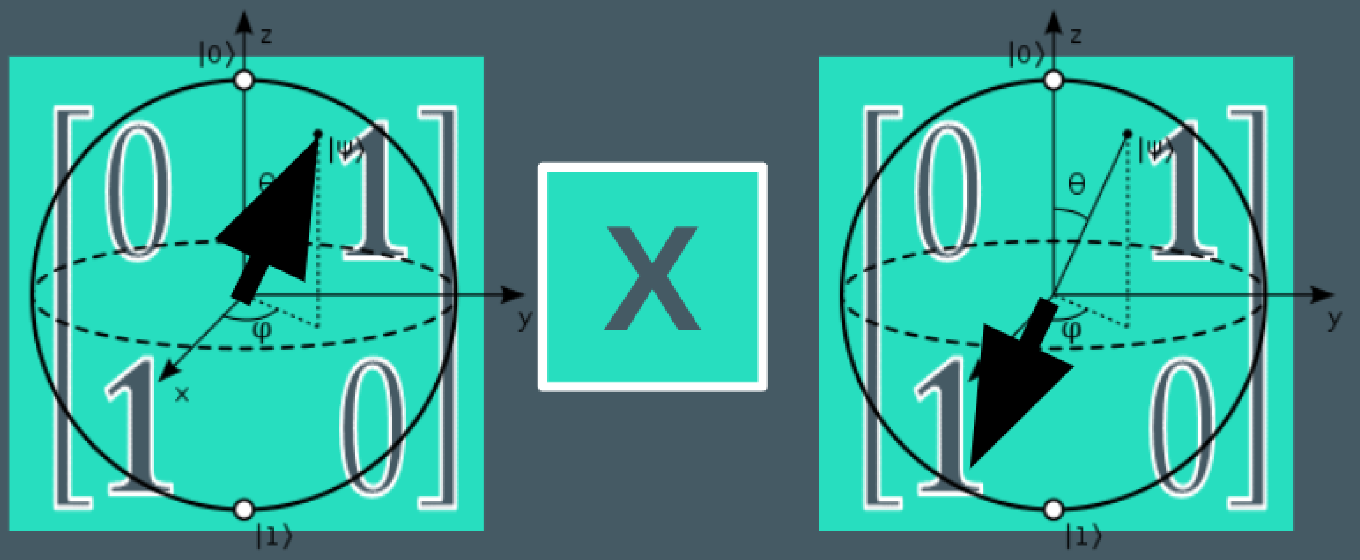
$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

(Pauli) X Gate,

$$-\boxed{X}-$$

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

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



$$|\Psi\rangle_{in} = \cos\left(\frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|1\rangle$$

a 180° rotation around the x-axis

$$|\Psi\rangle_{out} = \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|0\rangle + \cos\left(\frac{\theta}{2}\right)|1\rangle$$

$$|\Psi\rangle_{out} = \cos\left(\frac{\pi}{2} - \frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\pi}{2} - \frac{\theta}{2}\right)e^{-i\varphi}|1\rangle$$

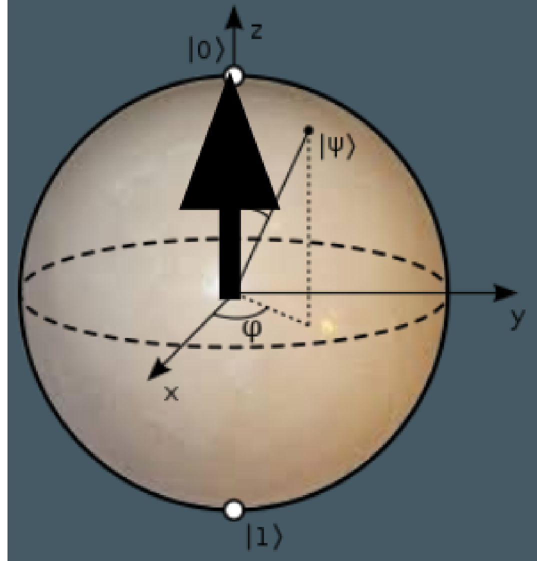
(Pauli) Z Gate,

— Z —

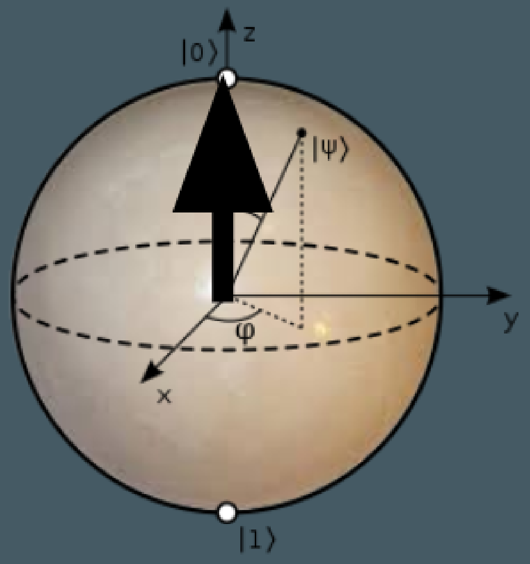
$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

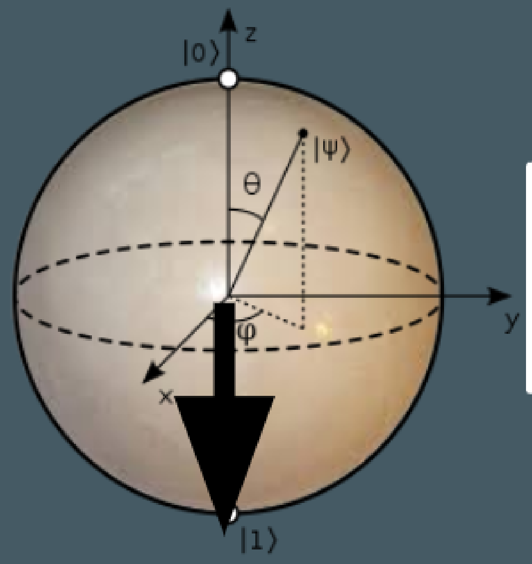
$|0\rangle$ — Z — $|0\rangle$

$|1\rangle$ — Z — $-|1\rangle$

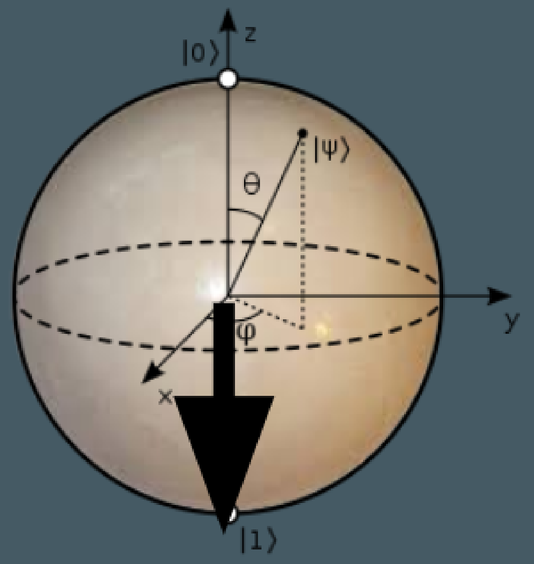


Z





Z



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

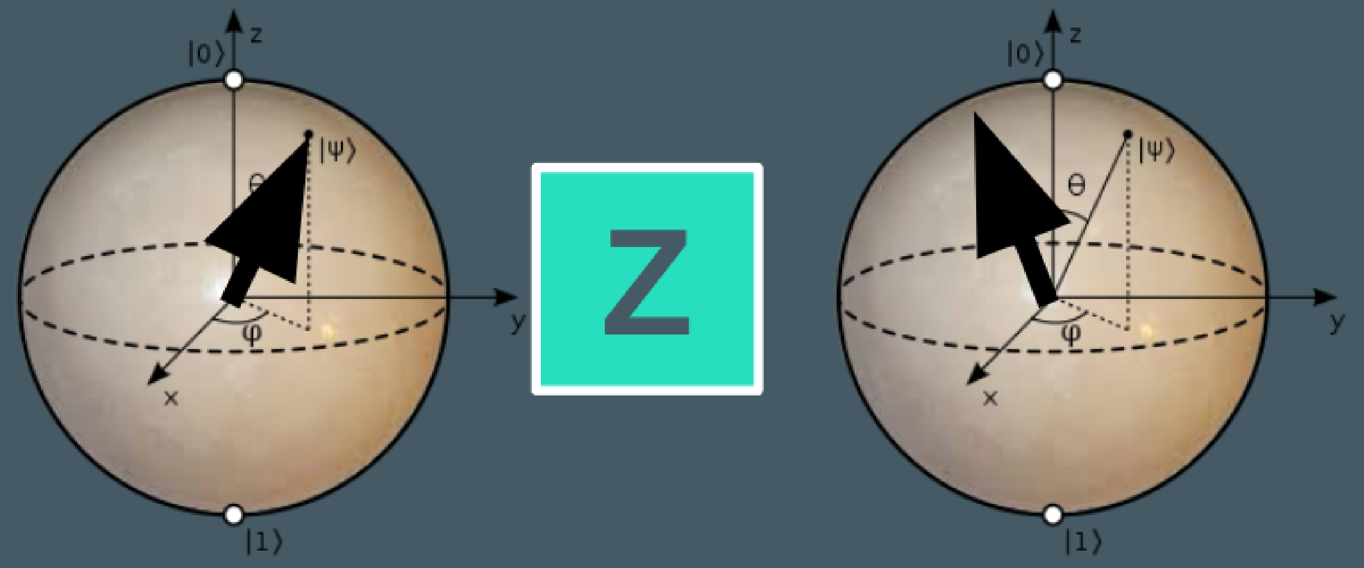
$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = -1 \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

(Pauli) Z Gate,

Z

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

$$\begin{bmatrix}1 & 0\\ 0 & -1\end{bmatrix}\begin{bmatrix}a\\ b\end{bmatrix} = \begin{bmatrix}a\\ -b\end{bmatrix}$$



a 180° rotation around the Z-axis

$$|\Psi\rangle_{in} = \cos\left(\frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|1\rangle$$

$$|\Psi\rangle_{out} = \cos\left(\frac{\theta}{2}\right)|0\rangle - \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|1\rangle$$

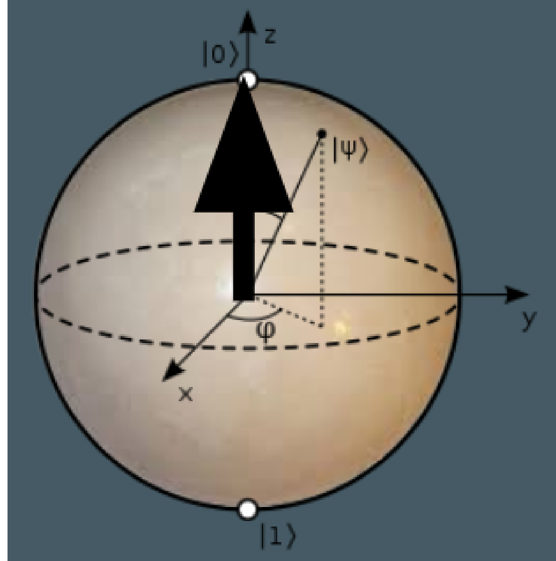
$$|\Psi\rangle_{out} = \cos\left(\frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\theta}{2}\right)e^{i(\varphi+\pi)}|1\rangle$$

(Pauli) Y Gate,

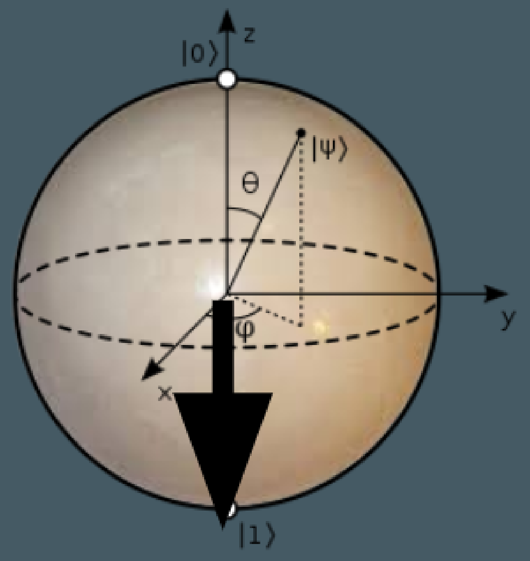
—[Y]—

$$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

$|0\rangle$ —[Y]— $i|1\rangle$

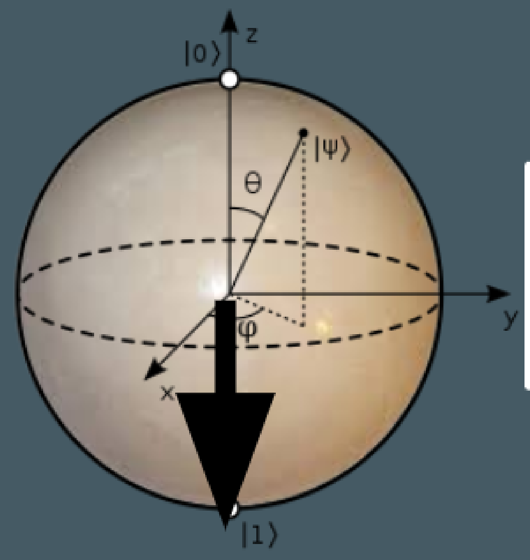


Y

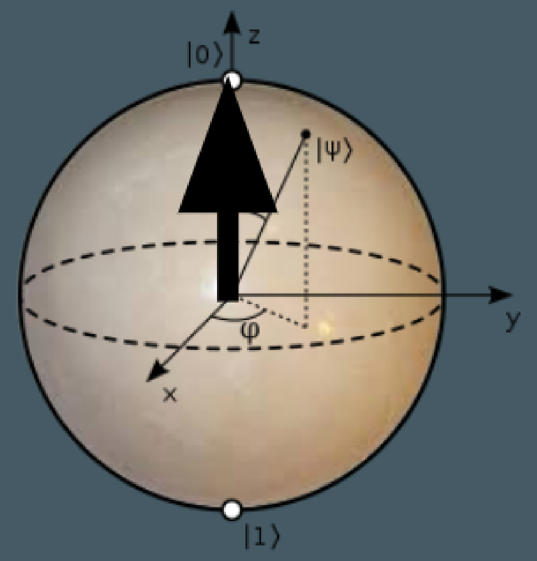


$$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = i \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$|1\rangle$ —[Y]— $-i|0\rangle$



Y



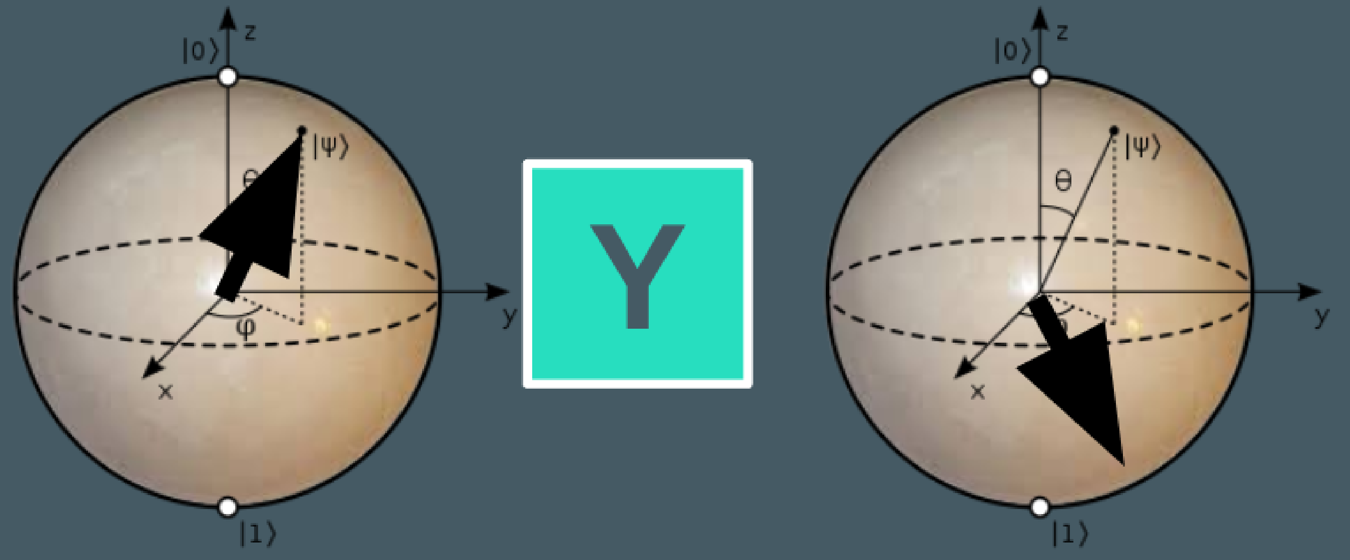
$$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = -i \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

(Pauli) Y Gate,

Y

$$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}\begin{bmatrix} a \\ b \end{bmatrix} = i\begin{bmatrix} -b \\ a \end{bmatrix}$$



a 180° rotation around the y-axis

$$|\Psi\rangle_{in} = \cos\left(\frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\theta}{2}\right)e^{i\varphi}|1\rangle$$

$$i|\Psi\rangle_{out} = -\sin\left(\frac{\theta}{2}\right)e^{i\varphi}|0\rangle + \cos\left(\frac{\theta}{2}\right)|1\rangle$$

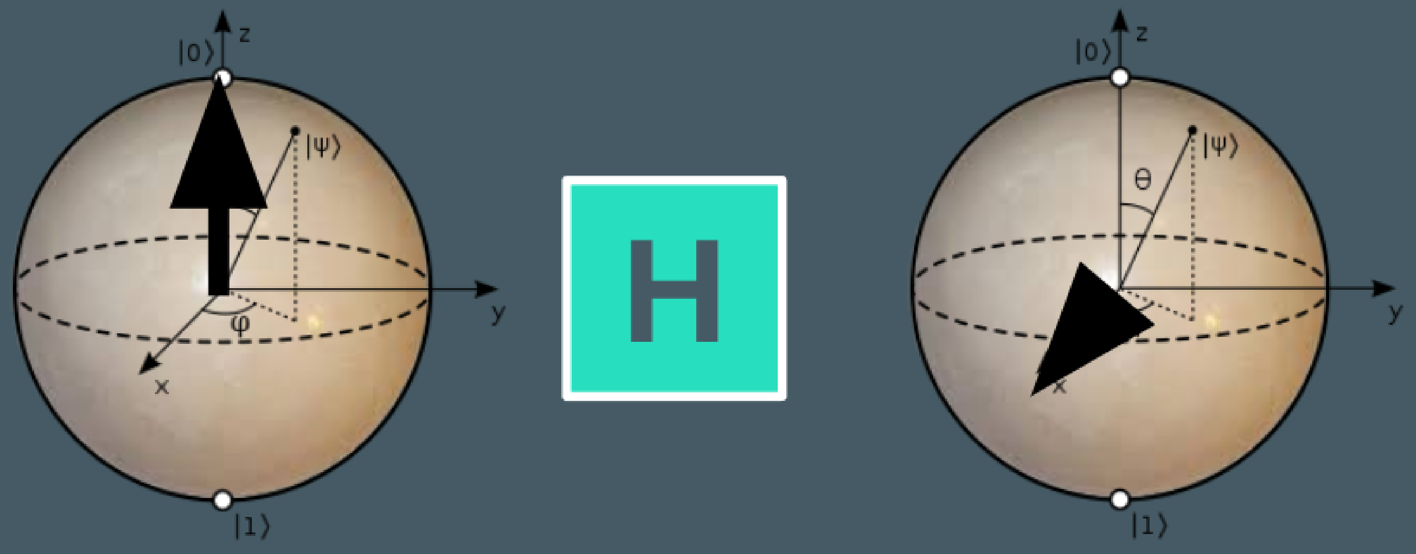
$$-i|\Psi\rangle_{out} = \cos\left(\frac{\pi}{2}-\frac{\theta}{2}\right)|0\rangle + \sin\left(\frac{\pi}{2}-\frac{\theta}{2}\right)e^{-i(\varphi+\pi)}|1\rangle$$

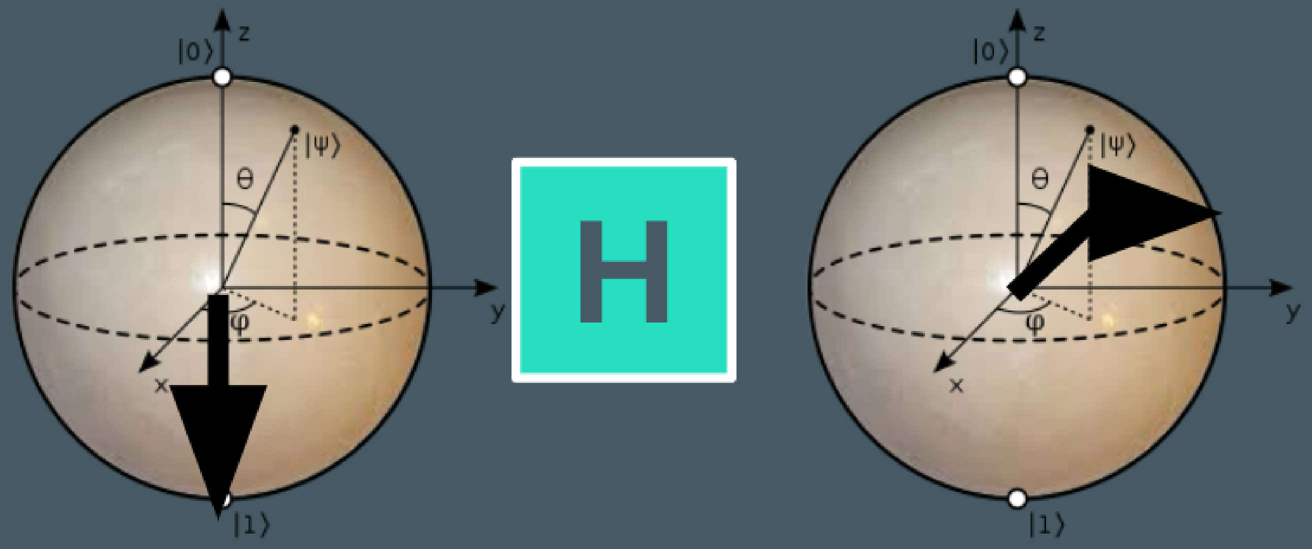
Hadamard Gate,

$$-\boxed{H}- \quad \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$|0\rangle - \boxed{H} - \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$|1\rangle - \boxed{H} - \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$$





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

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

Make a superposition state

Other Gates

S

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

"S gate"

Phase different = $\pi/2$

T

$$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{bmatrix}$$

"T gate"

Phase different = $\pi/4$

U

$$\begin{bmatrix} U_{11} & U_{12} \\ U_{21} & U_{22} \end{bmatrix}$$

"U gate"

a general rotation

2-qubits state

2 Qubits

$|\Psi 1\rangle = a|0\rangle + b|1\rangle$

$|\Psi 2\rangle = u|0\rangle + v|1\rangle$

Ket form

$$|\Psi\rangle_{total} = \alpha|0,0\rangle + \beta|0,1\rangle + \gamma|1,0\rangle + \delta|1,1\rangle$$

qubit2 qubit1

4 complex numbers

$$|\Psi\rangle_{total} = \begin{bmatrix} \alpha \\ \beta \\ \gamma \\ \delta \end{bmatrix}$$

Matrix form

2 Bits

4 states

2-qubits state

$$|\Psi1\rangle = a1|0\rangle + b1|1\rangle$$

$$|\Psi2\rangle = a2|0\rangle + b2|1\rangle$$

$$= \begin{bmatrix} a2 \\ b2 \end{bmatrix} \otimes \begin{bmatrix} a1 \\ b1 \end{bmatrix}$$

$$|\Psi\rangle_{total} = |\Psi1\rangle \otimes |\Psi2\rangle = (a1 * a2)|0,0\rangle + (b1 * a2)|0,1\rangle + (a1 * b2)|1,0\rangle + (b1 * b2)|1,1\rangle$$

$$= \alpha|0,0\rangle + \beta|0,1\rangle + \gamma|1,0\rangle + \delta|1,1\rangle$$

qubit2 qubit1

Matrix 4x1

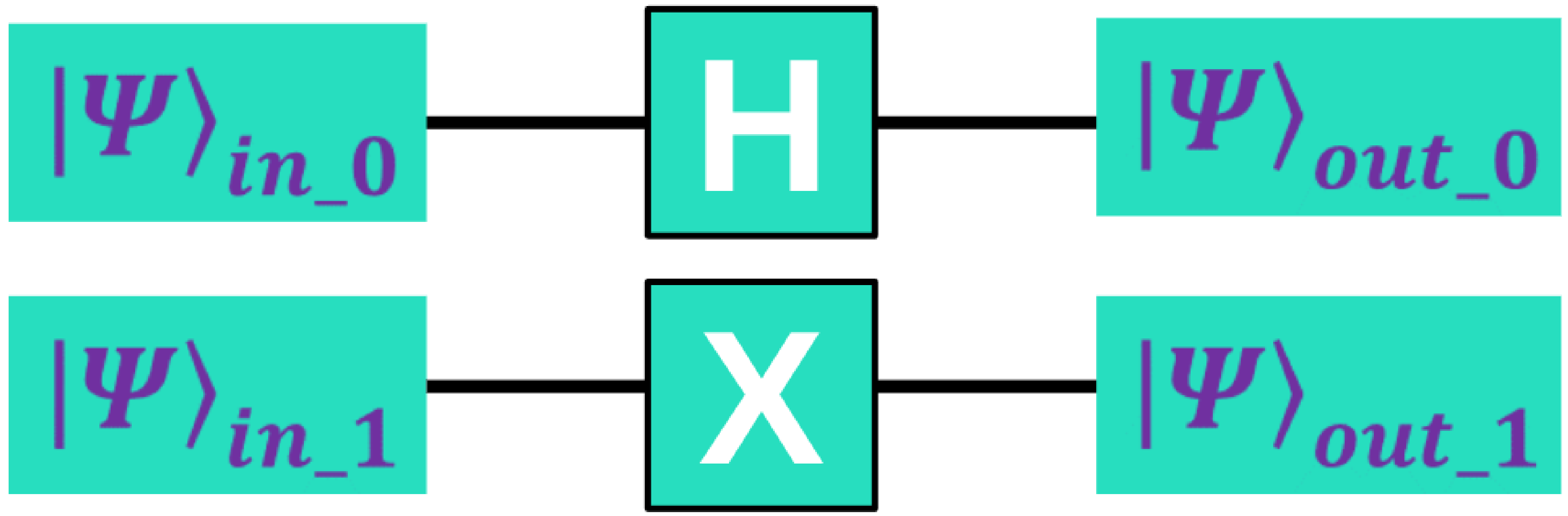
$$|\Psi\rangle_{total} = \begin{bmatrix} \alpha = a1 * a2 \\ \beta = b1 * a2 \\ \gamma = a1 * b2 \\ \delta = b1 * b2 \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} a1 \\ b1 \end{bmatrix} * a2 \\ \begin{bmatrix} a1 \\ b1 \end{bmatrix} * b2 \end{bmatrix} \Leftrightarrow U_{2qbits} = \begin{bmatrix} U_{11} & U_{12} & U_{13} & U_{14} \\ U_{21} & U_{22} & U_{23} & U_{24} \\ U_{31} & U_{32} & U_{33} & U_{34} \\ U_{41} & U_{42} & U_{43} & U_{44} \end{bmatrix}$$

2-qubits gate

Matrix 4x4

2-Qubits Gate

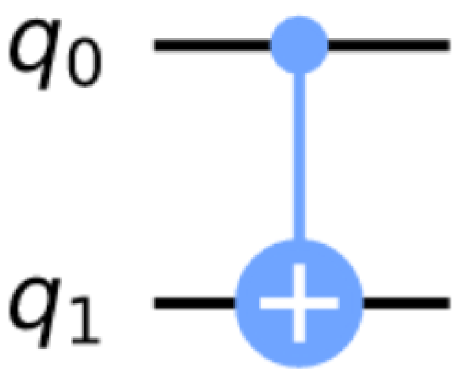
Example



$$X|q_1\rangle \otimes H|q_0\rangle = (X \otimes H)|q_1 q_0\rangle$$

$$X \otimes H = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \otimes \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 \times \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} & 1 \times \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \\ 1 \times \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} & 0 \times \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix}$$

The CNOT-Gate



q_0 *is called "control qubit"*

q_1 *is called "target qubit"*

input		output	
c	t	c	t
0	0	0	0
0	1	0	1
1	0	1	1
1	1	1	0

qubit1 qubit0

$$|\Psi\rangle_{input} = \alpha|0,0\rangle + \beta|0,1\rangle + \gamma|1,0\rangle + \delta|1,1\rangle$$

$$CNOT|\Psi\rangle_{input} = \alpha|0,0\rangle + \delta|0,1\rangle + \gamma|1,0\rangle + \beta|1,1\rangle$$

$$|\Psi\rangle_{total} = \begin{bmatrix} \alpha \\ \beta \\ \gamma \\ \delta \end{bmatrix} \quad CNOT|\Psi\rangle_{total} = \begin{bmatrix} \alpha \\ \delta \\ \gamma \\ \beta \end{bmatrix}$$

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

Swap gate

qubit1 qubit0

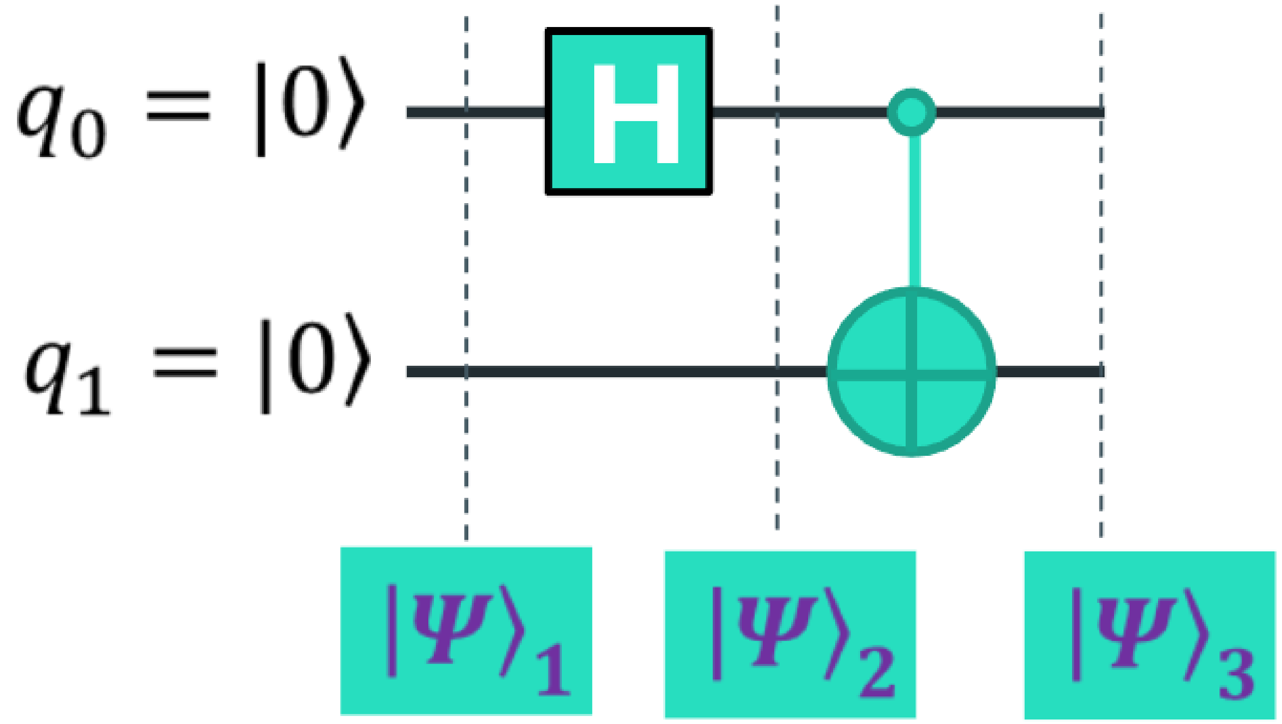
$$|\Psi\rangle_{input} = \alpha|0,0\rangle + \beta|0,1\rangle + \gamma|1,0\rangle + \delta|1,1\rangle$$

$$SWAP|\Psi\rangle_{input} = \alpha|0,0\rangle + \gamma|0,1\rangle + \beta|1,0\rangle + \delta|1,1\rangle$$

$$|\Psi\rangle_{total} = \begin{bmatrix} \alpha \\ \beta \\ \gamma \\ \delta \end{bmatrix} \qquad SWAP|\Psi\rangle_{total} = \begin{bmatrix} \alpha \\ \gamma \\ \beta \\ \delta \end{bmatrix}$$

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

Bell state



q_0 *is called "control qubit"*

q_1 *is called "target qubit"*

$$|\Psi\rangle_1 = |0\rangle \otimes |0\rangle$$

$$|\Psi\rangle_2 = |0\rangle \otimes H|0\rangle = |0\rangle \otimes \left(\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle\right) = \frac{1}{\sqrt{2}}|0,0\rangle + \frac{1}{\sqrt{2}}|0,1\rangle$$

$$|\Psi\rangle_3 = CNOT\left(\frac{1}{\sqrt{2}}|0,0\rangle + \frac{1}{\sqrt{2}}|0,1\rangle\right) = \frac{1}{\sqrt{2}}|0,0\rangle + \frac{1}{\sqrt{2}}|1,1\rangle$$

$$\boxed{|\Phi^+\rangle = \frac{1}{\sqrt{2}}|0,0\rangle + \frac{1}{\sqrt{2}}|1,1\rangle}$$

Entanglement state

4 Bell states

$$|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_B + |1\rangle_A \otimes |1\rangle_B) \quad (1)$$

$$|\Phi^-\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_B - |1\rangle_A \otimes |1\rangle_B) \quad (2)$$

$$|\Psi^+\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B) \quad (3)$$

$$|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |1\rangle_B - |1\rangle_A \otimes |0\rangle_B). \quad (4)$$

Entanglement states

$$|0,0\rangle = \frac{1}{\sqrt{2}}|\Phi^+\rangle + \frac{1}{\sqrt{2}}|\Phi^-\rangle$$

$$\left|1,1\right\rangle = \frac{1}{\sqrt{2}}\left|\Phi^+\right\rangle - \frac{1}{\sqrt{2}}|\Phi^-\rangle$$

$$|0,1\rangle = \frac{1}{\sqrt{2}}|\Psi^+\rangle + \frac{1}{\sqrt{2}}|\Psi^-\rangle$$

$$\left|1,0\right\rangle = \frac{1}{\sqrt{2}}\left|\Psi^+\right\rangle - \frac{1}{\sqrt{2}}|\Psi^-\rangle$$

Bell states measurement

$|0,0\rangle$ $|0,1\rangle$ $|1,0\rangle$ $|1,1\rangle$

4 measurement outcomes

$$|\Psi\rangle_{2qubits} = \alpha|0,0\rangle + \beta|0,1\rangle + \gamma|1,0\rangle + \delta|1,1\rangle$$

$$|\Psi\rangle_{2qubits} = a|\Phi^+\rangle + \mathrm{b}|\Phi^-\rangle + c|\Psi^+\rangle + d|\Psi^-\rangle$$

4 measurement outcomes

$|\Phi^+\rangle$ $|\Phi^-\rangle$ $|\Psi^+\rangle$ $|\Psi^-\rangle$

1 qubit measurement

Basis 0,1

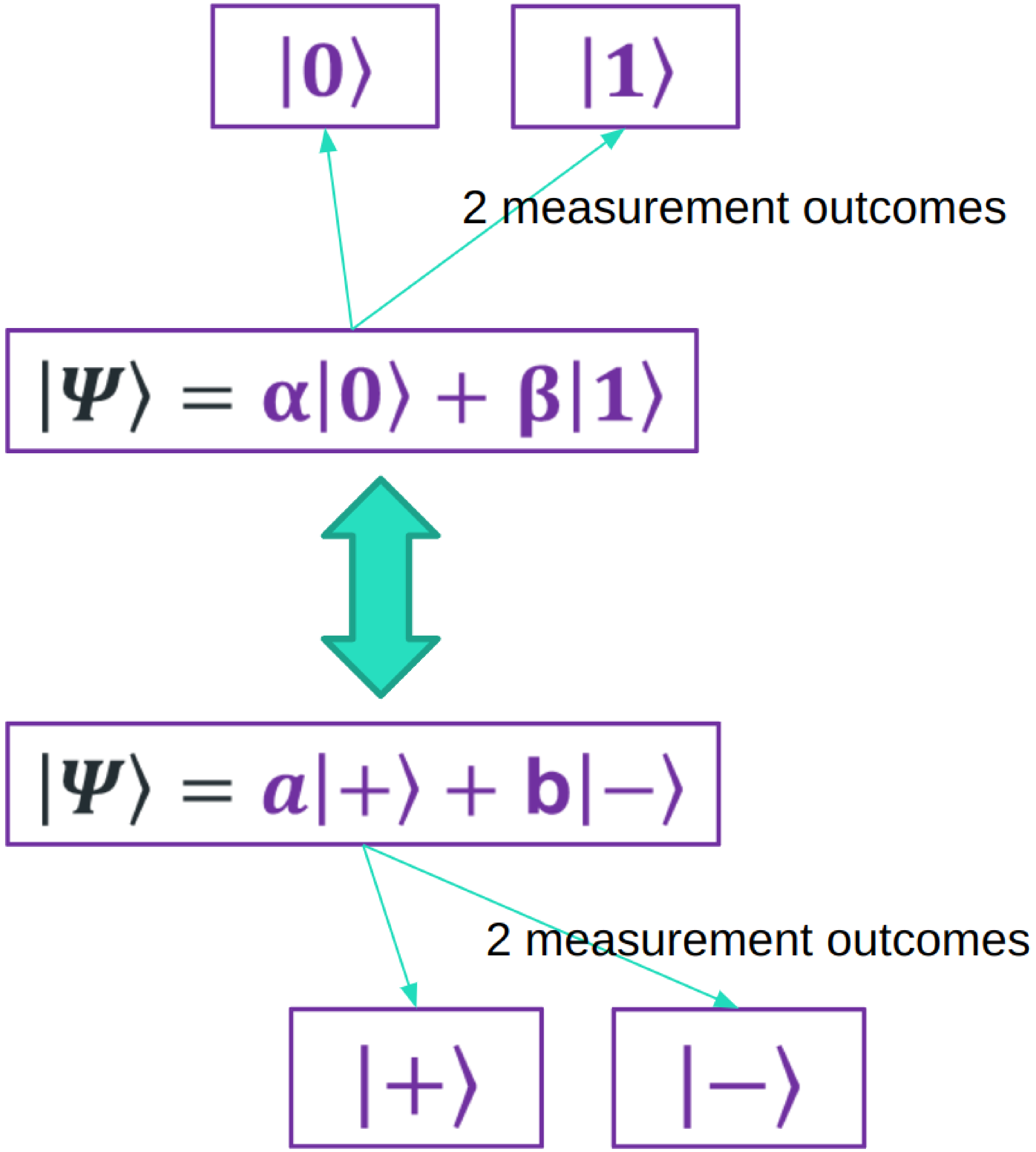
$$|+\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$|-\rangle = \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$$

Basis +, -

$$|0\rangle = \frac{1}{\sqrt{2}}|+\rangle + \frac{1}{\sqrt{2}}|-\rangle$$

$$|1\rangle = \frac{1}{\sqrt{2}}|+\rangle - \frac{1}{\sqrt{2}}|-\rangle$$



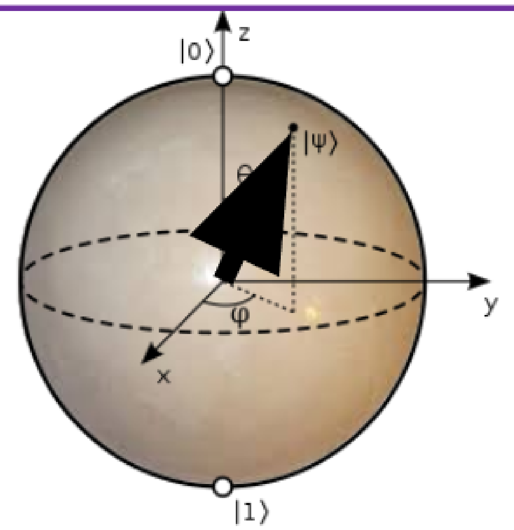
Quantum Measurement

✔ 50:50 ✔ 70:30

Toss the coin 1,000,000 times and record
the number outcome is 0: the number outcome is 1

Probability

$|\Psi\rangle = a|0\rangle + b|1\rangle$



$|1\rangle$

$|0\rangle$

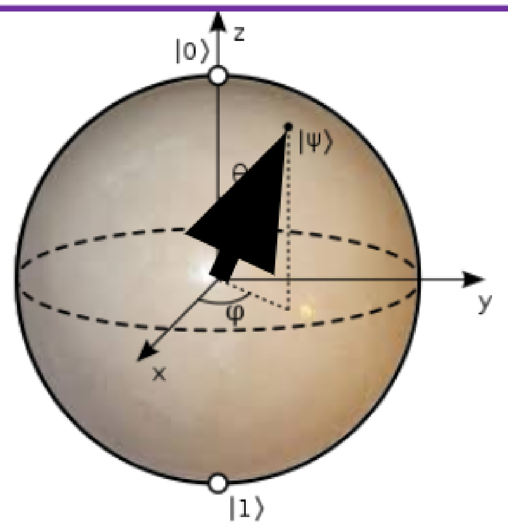
Measure qubits 1,000,000 qubits and record
the number outcome is |0>: the number outcome is |1>

$\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ $\lvert 0\rangle$ ... $\lvert a\rvert^2$	$\lvert 1\rangle$ $\lvert 1\rangle$ $\lvert 1\rangle$ $\lvert 1\rangle$ ... $\lvert b\rvert^2$

Probability

Quantum Measurement

$|\Psi\rangle = a|0\rangle + b|1\rangle$



$|1\rangle$

$|0\rangle$

Measurement many qubit!

$$Prob(|1\rangle) = |b|^2$$

$$Prob(|0\rangle) = |a|^2$$

Speed up: Superposition

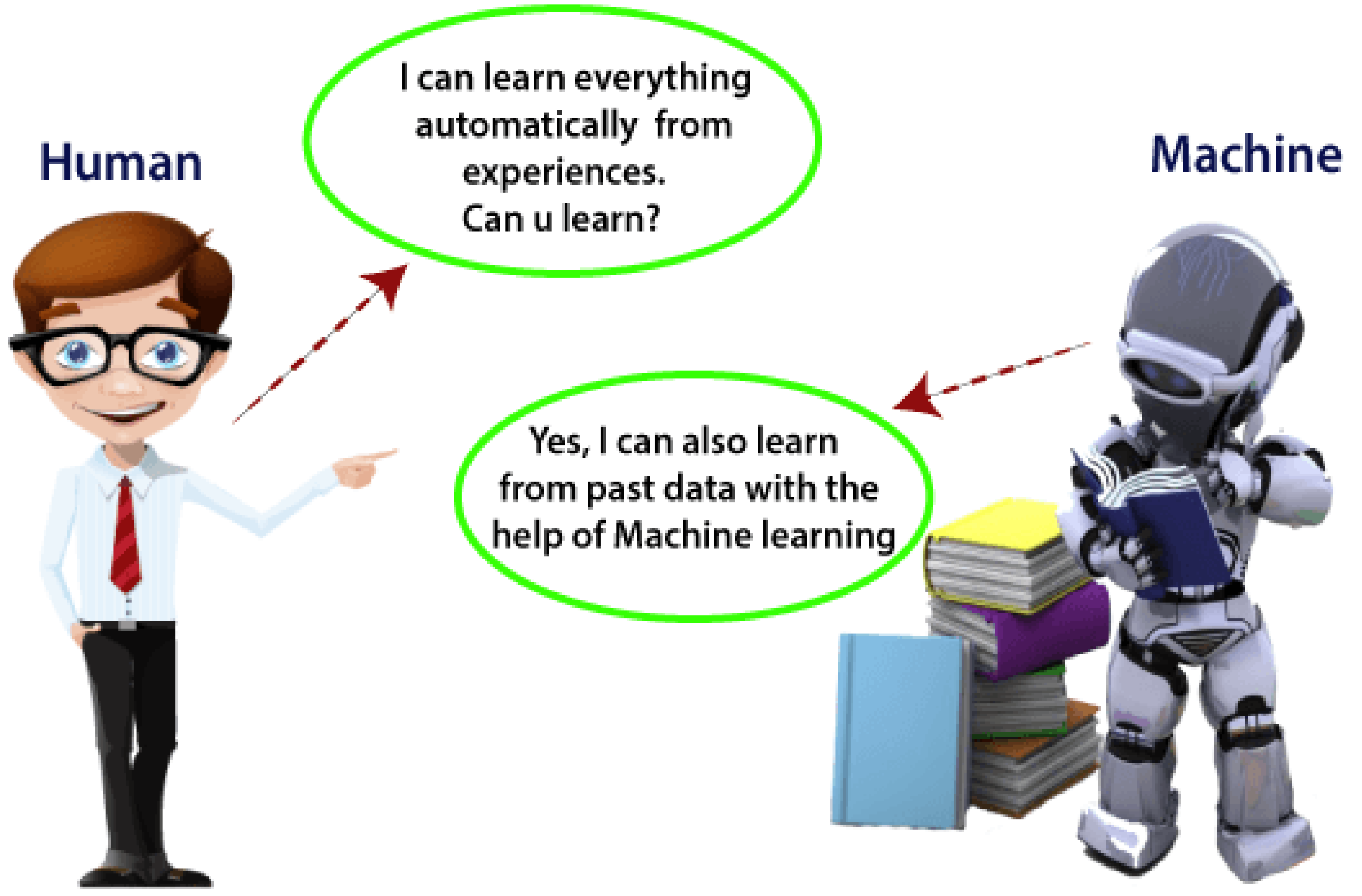
Slow down: Repetitive Measurement

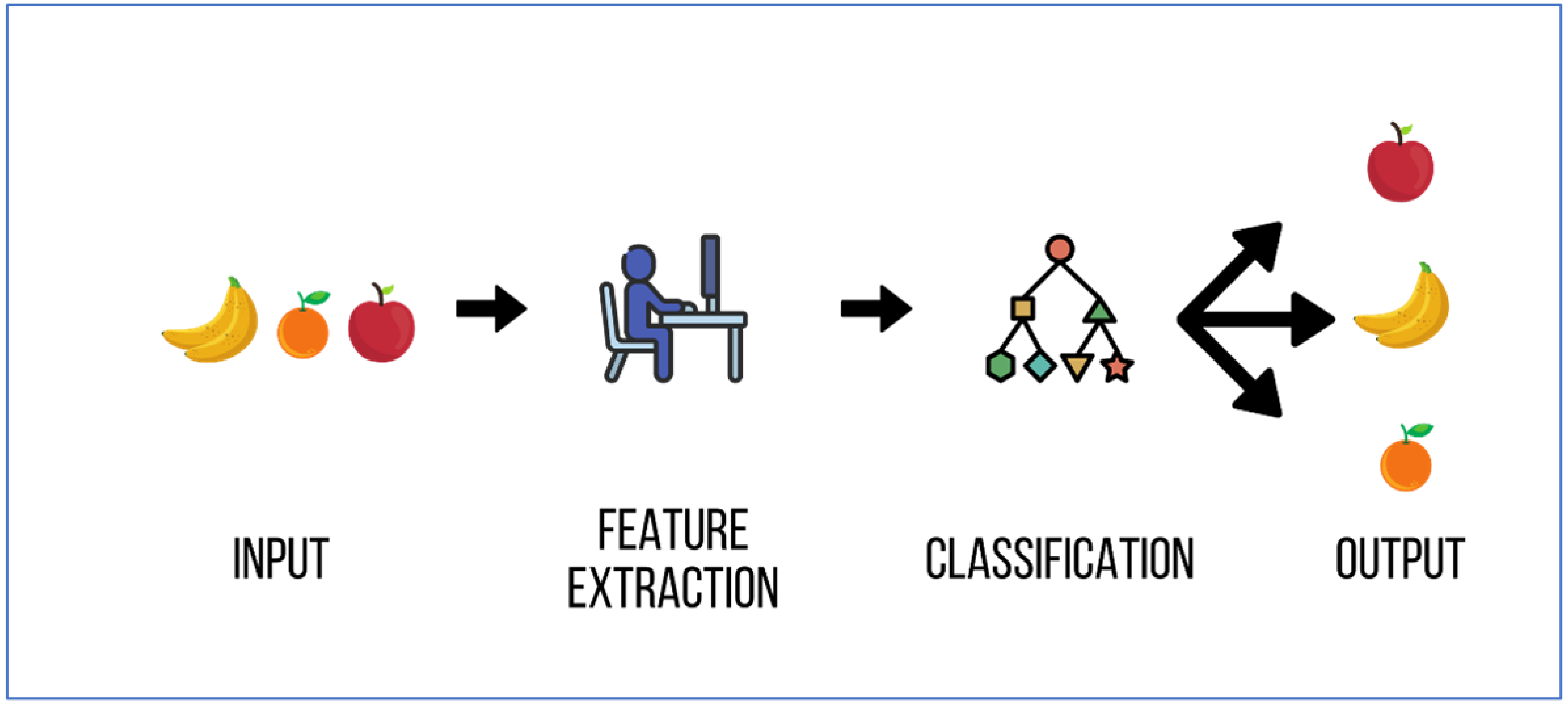
Coding time... with

Qiskit

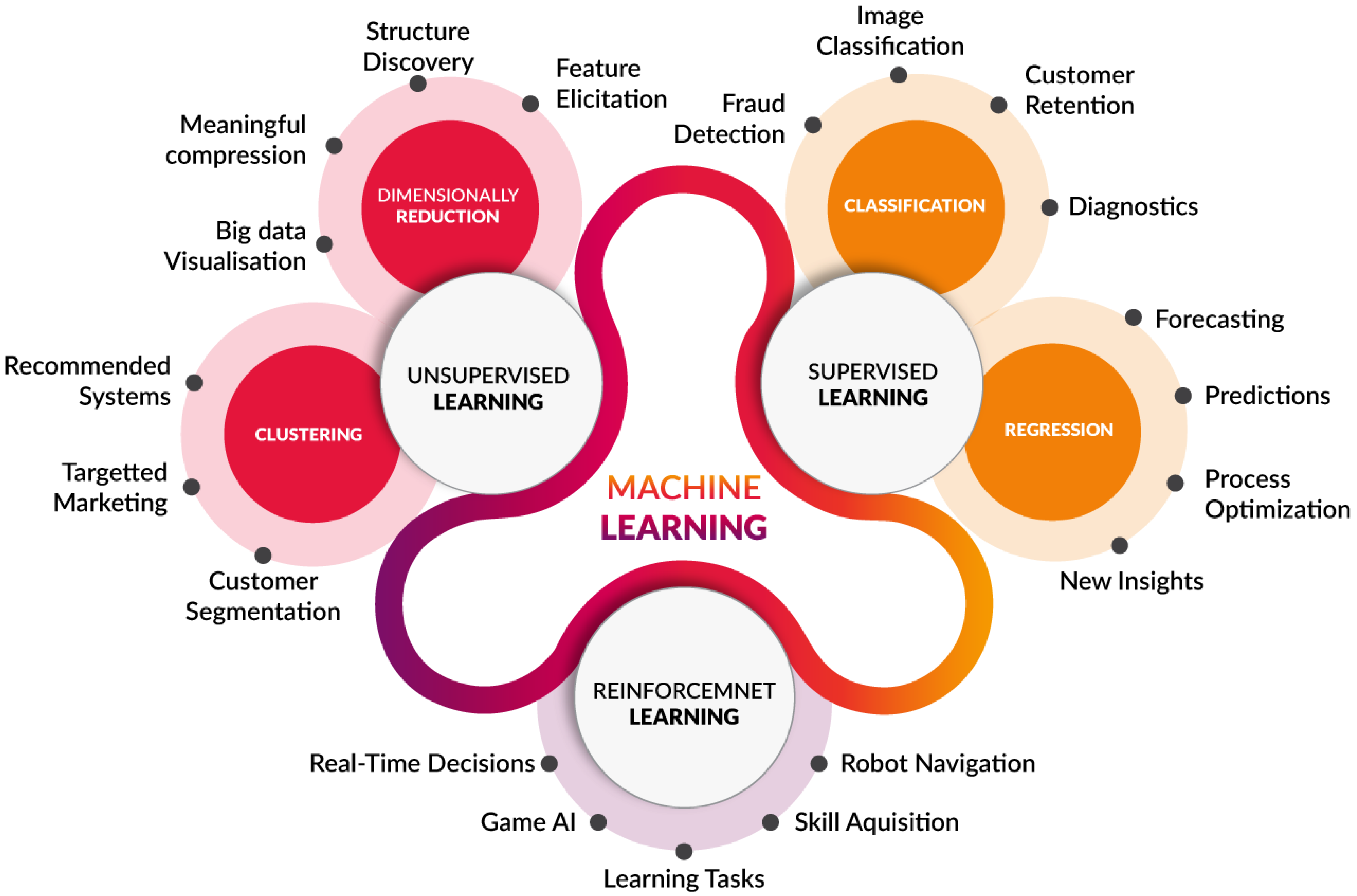
https://github.com/the-scamper/intro_quantum_ml

Intro to Machine Learning

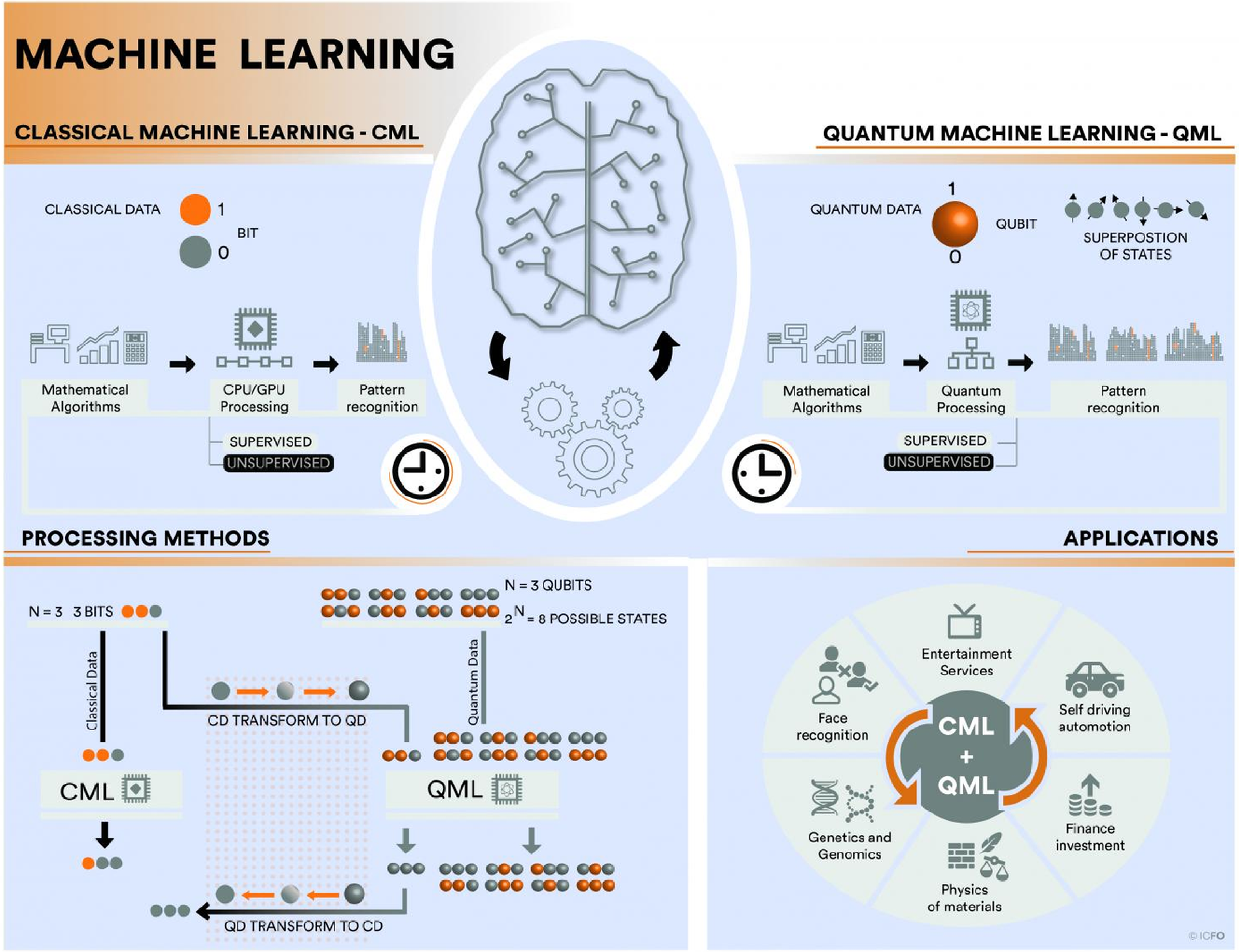




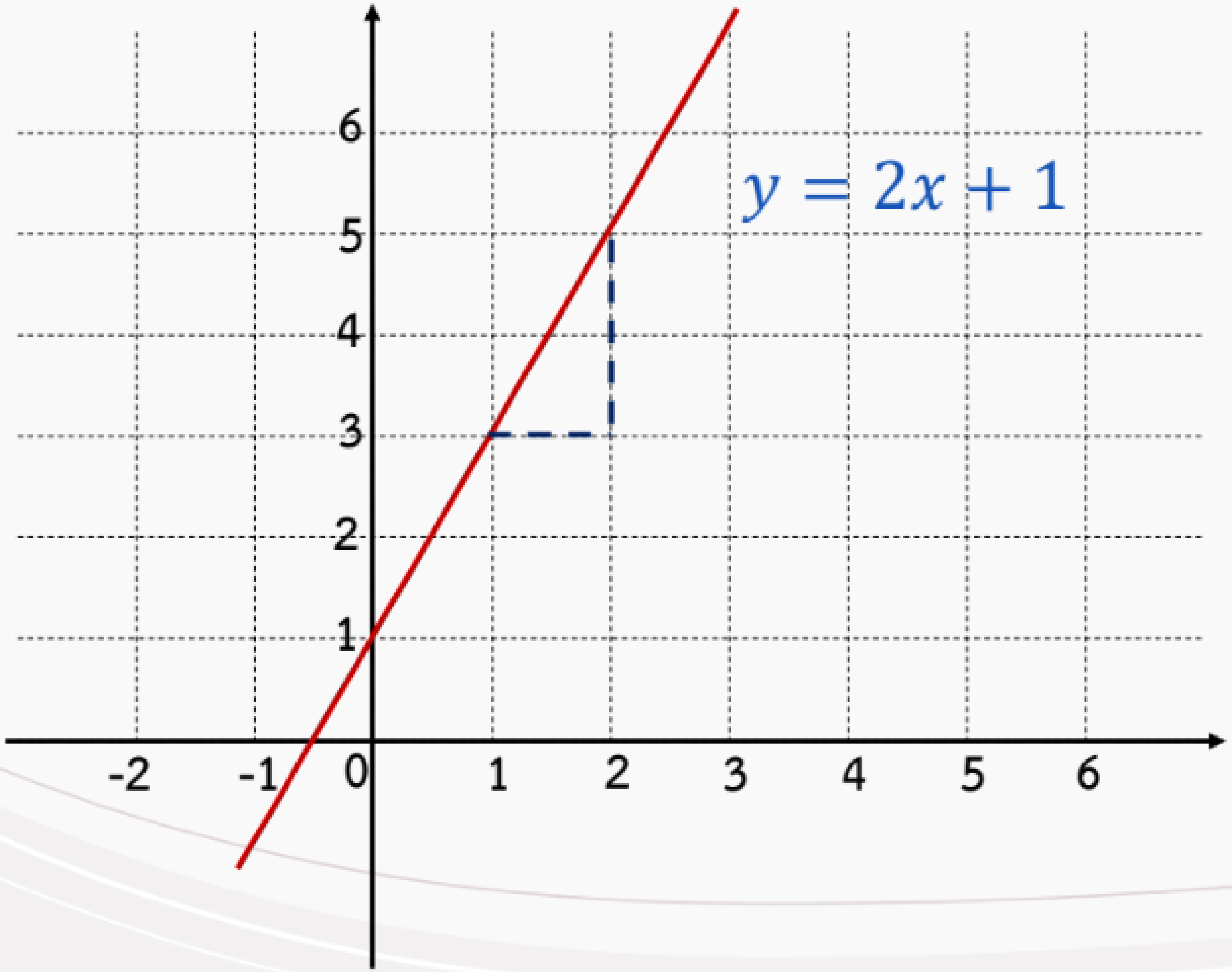
Intro to Machine Learning



Why Quantum Machine Learning



Equation of linear line

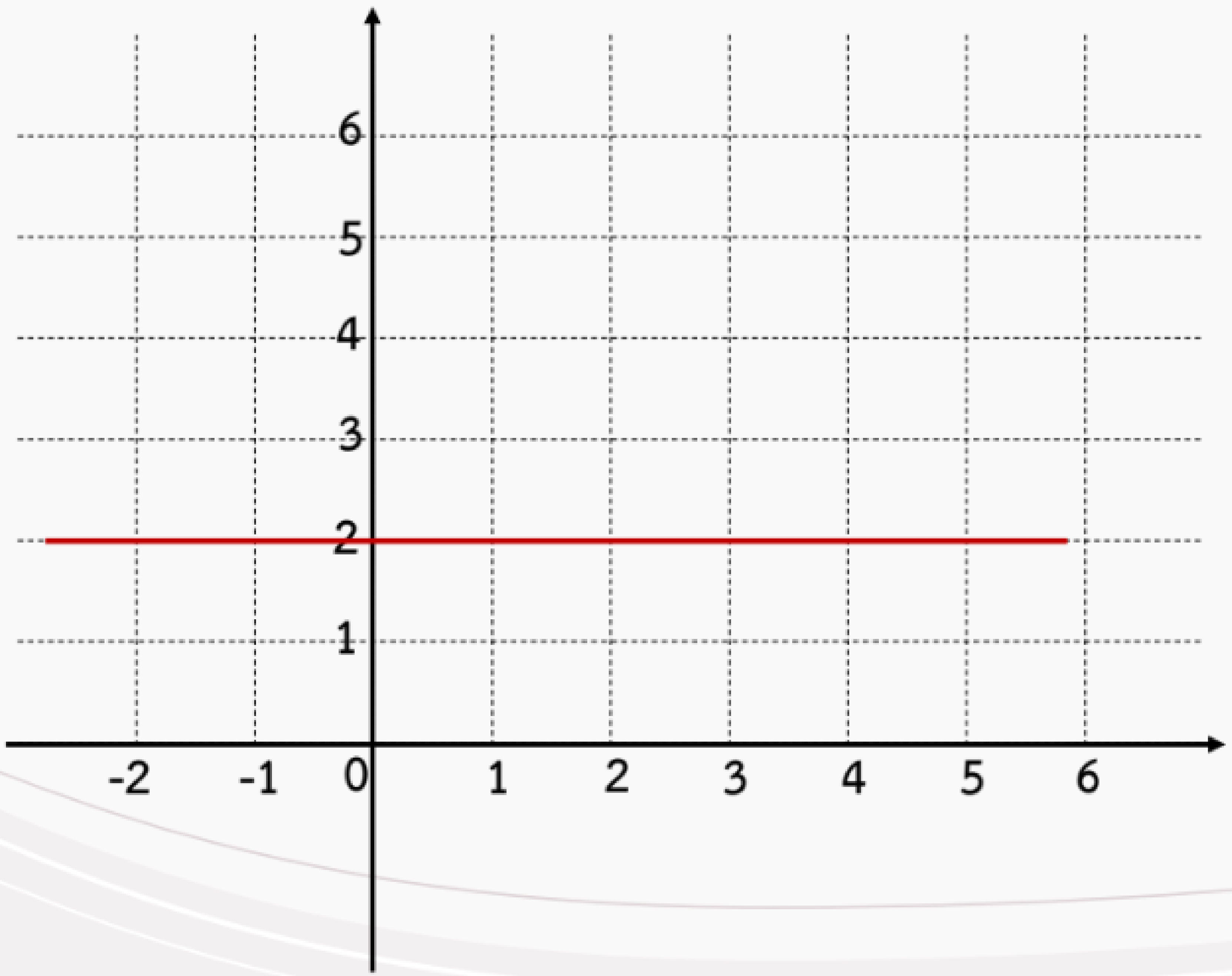


slope

$$y = mx + c$$

Y-intercept

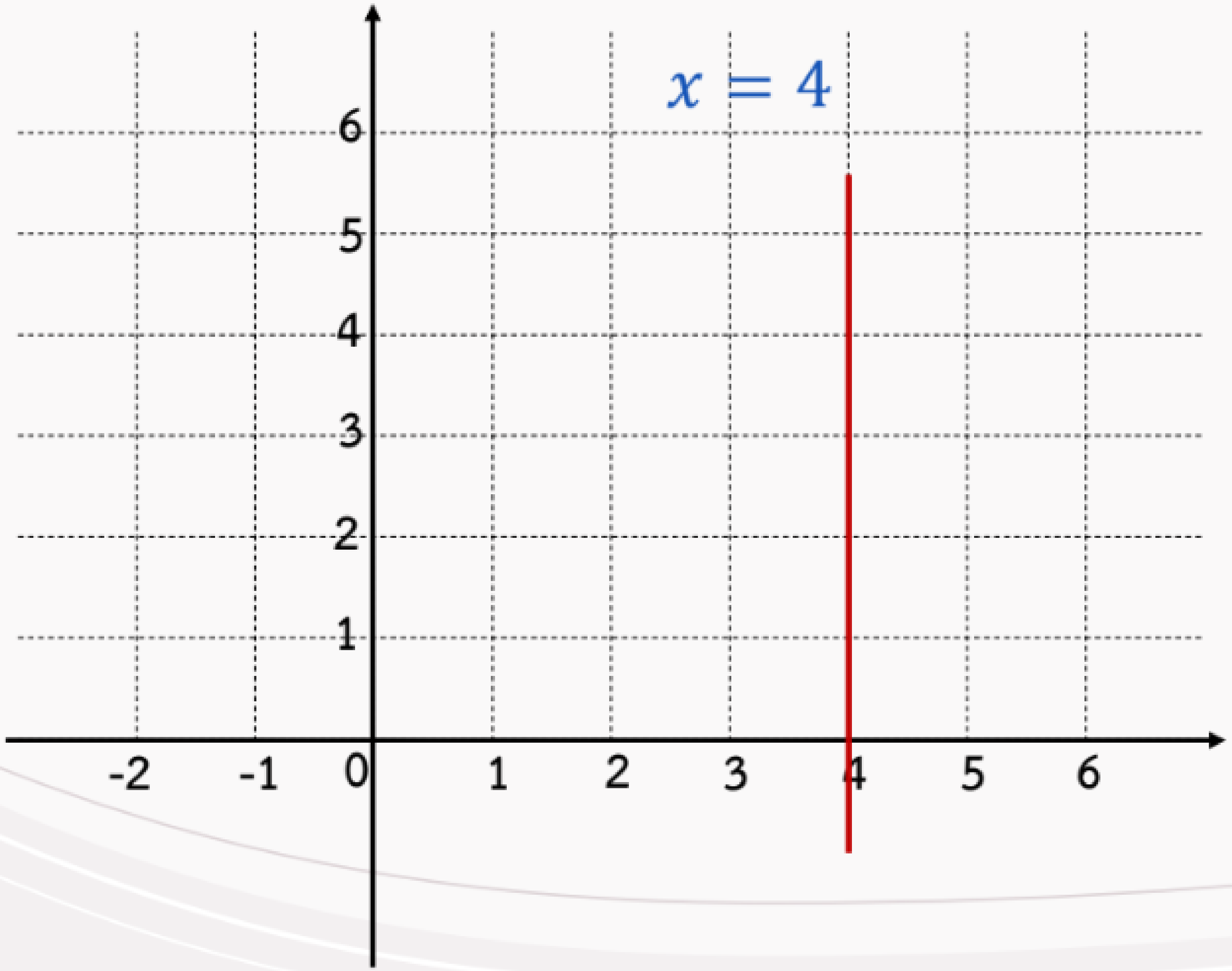
Equation of linear line



$$y = mx + c$$

$$y = 2$$

Equation of linear line



$$y = mx + c$$

$$Ax + By + C = 0$$

$$y = -\frac{A}{B}x - \frac{C}{B}$$

Equation of linear line

$$y = 2x + 1$$

$$-2x + y - 1 = 0$$

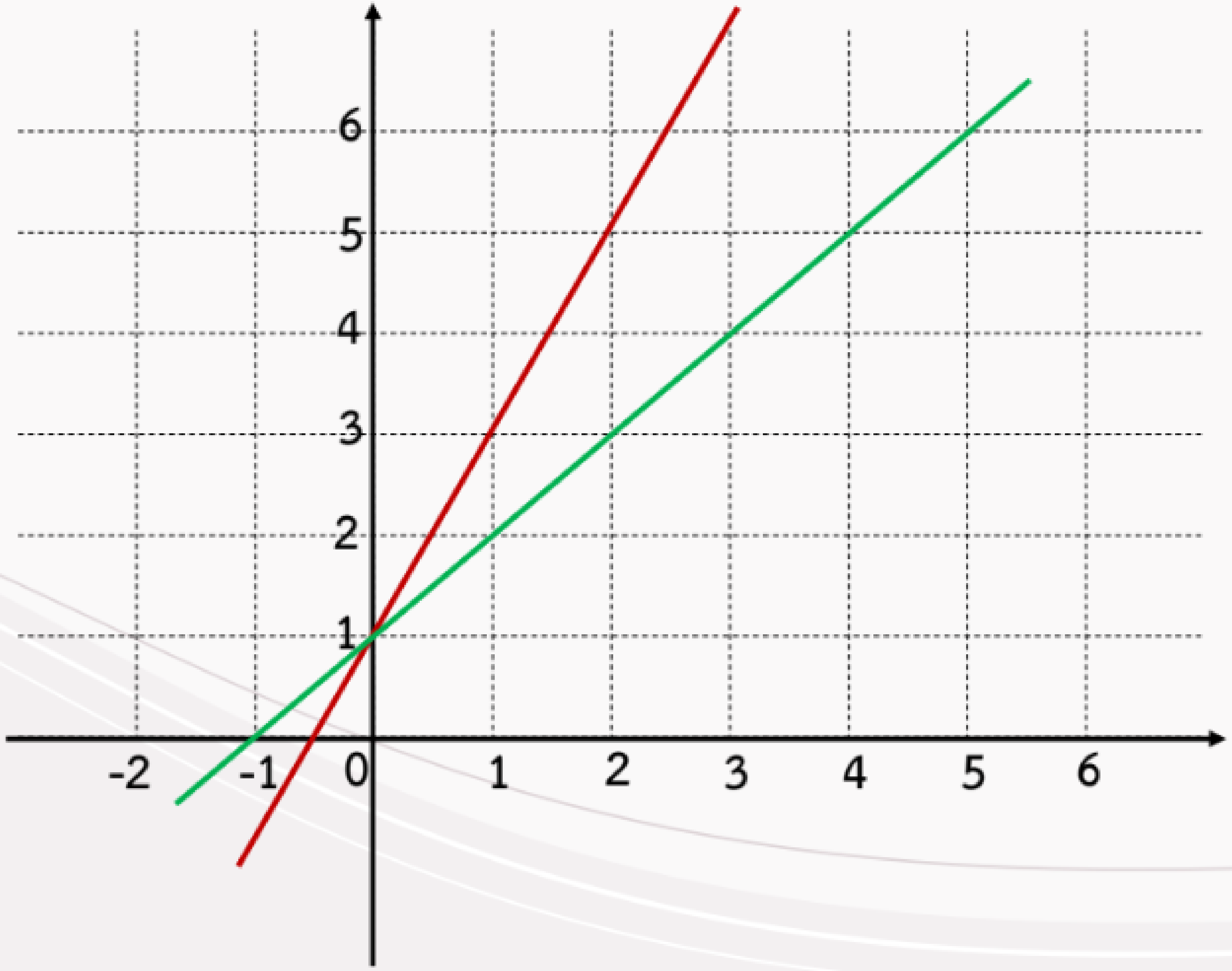
$$2 \times (-2x + y - 1 = 0)$$

$$-4x + 2y - 2 = 0$$

Equation of linear line

$$Ax + By + C = 0$$

$$y = -\frac{A}{B}x - \frac{C}{B}$$



$$-4x + 2y - 2 = 0$$

$$-2x + 2y - 2 = 0$$

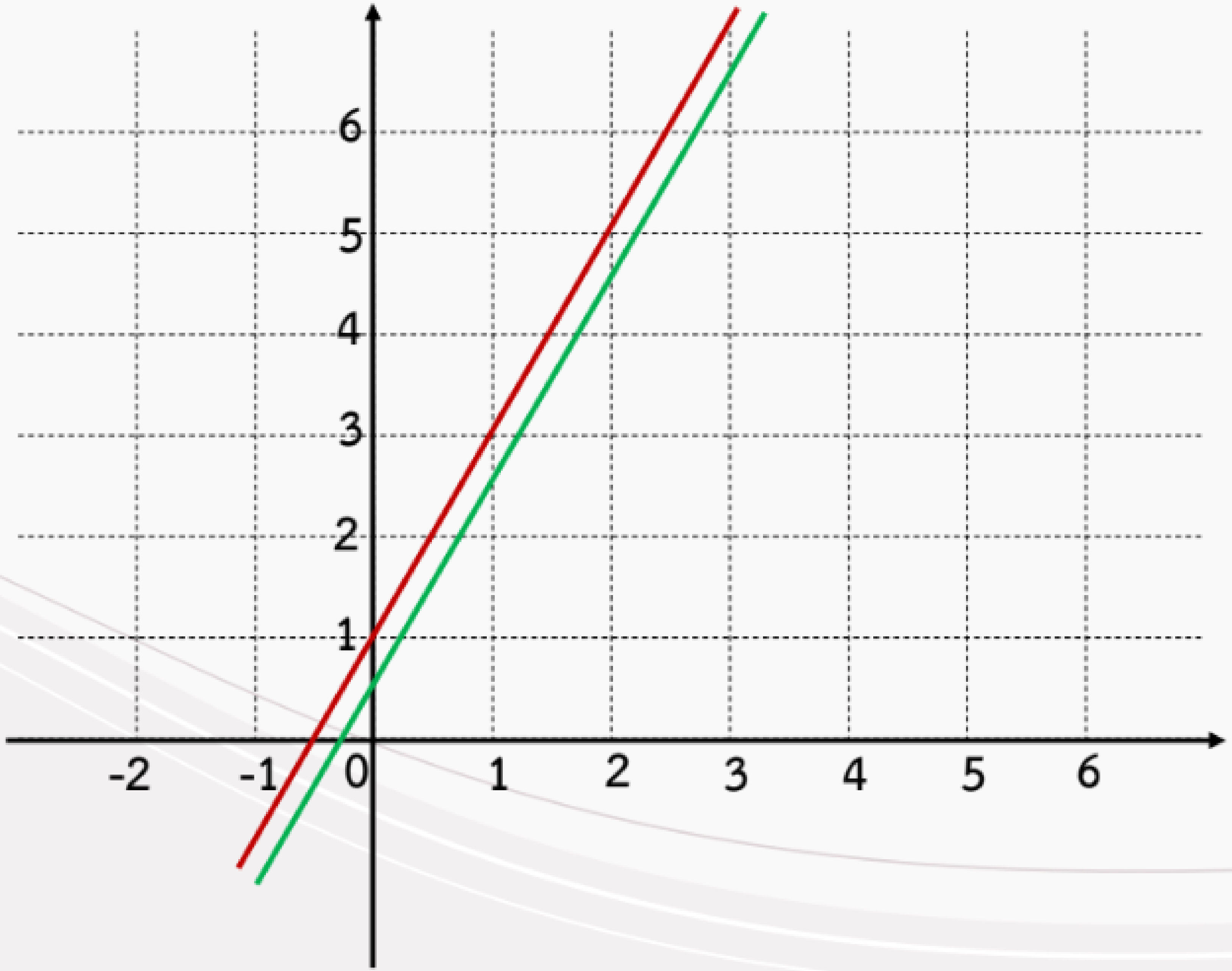
$$y = x + 1$$

$$y = -\frac{-2}{2}x - \frac{-2}{2}$$

Equation of linear line

$$Ax + By + C = 0$$

$$y = -\frac{A}{B}x - \frac{C}{B}$$



$$-4x + 2y - 2 = 0$$

$$-4x + 2y - 1 = 0$$

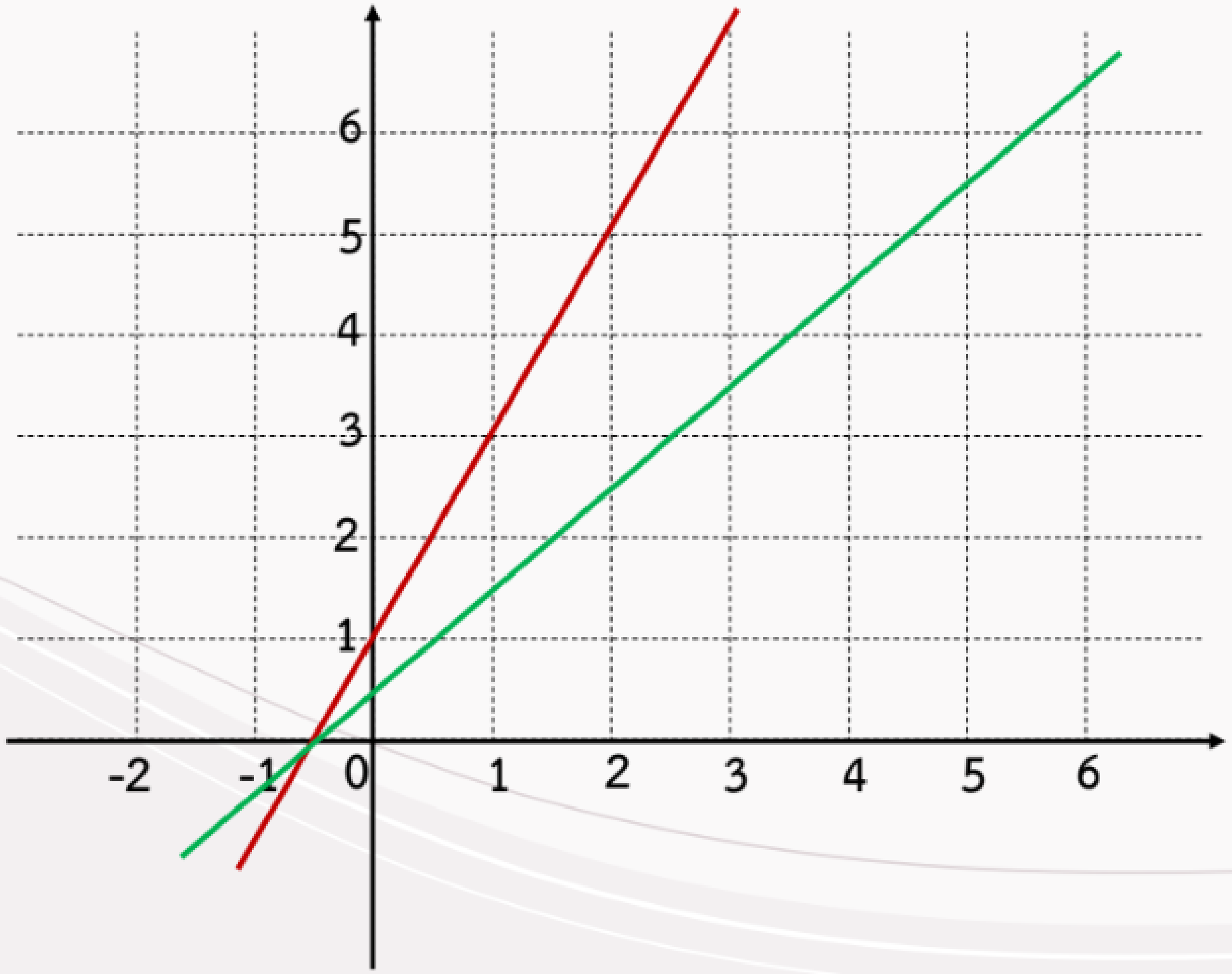
$$y = 2x + 0.5$$

$$y = -\frac{-4}{2}x - \frac{-2}{2}$$

Equation of linear line

$Ax + By + C = 0$

$y = -\frac{A}{B}x - \frac{C}{B}$



$-4x_1 + 2x_2 - 2$

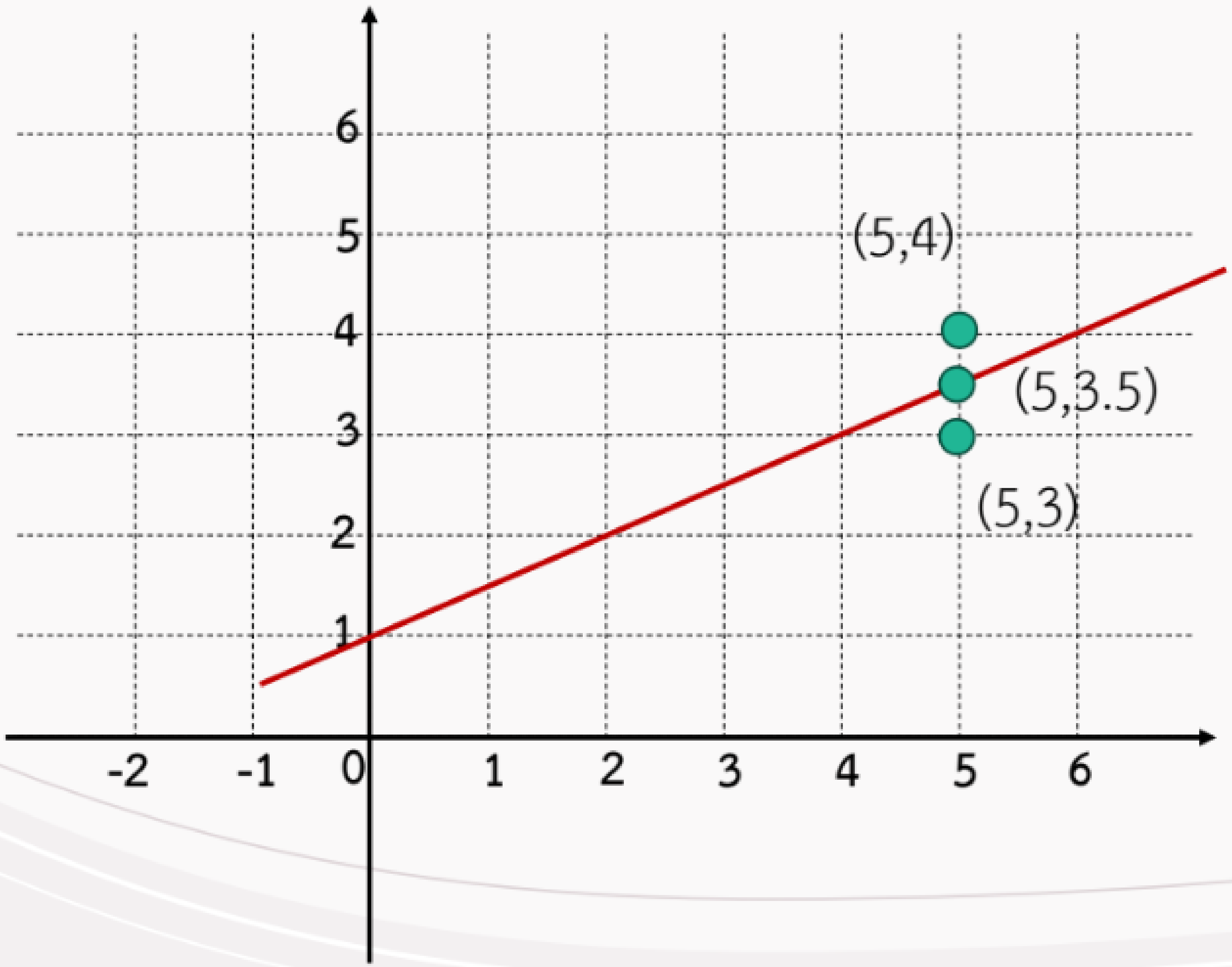
$-4x + 2y - 2 = 0$

$-4x + 4y - 2 = 0$

$y = x + 0.5$

$y = -\frac{-4}{4}x - \frac{-2}{4}$

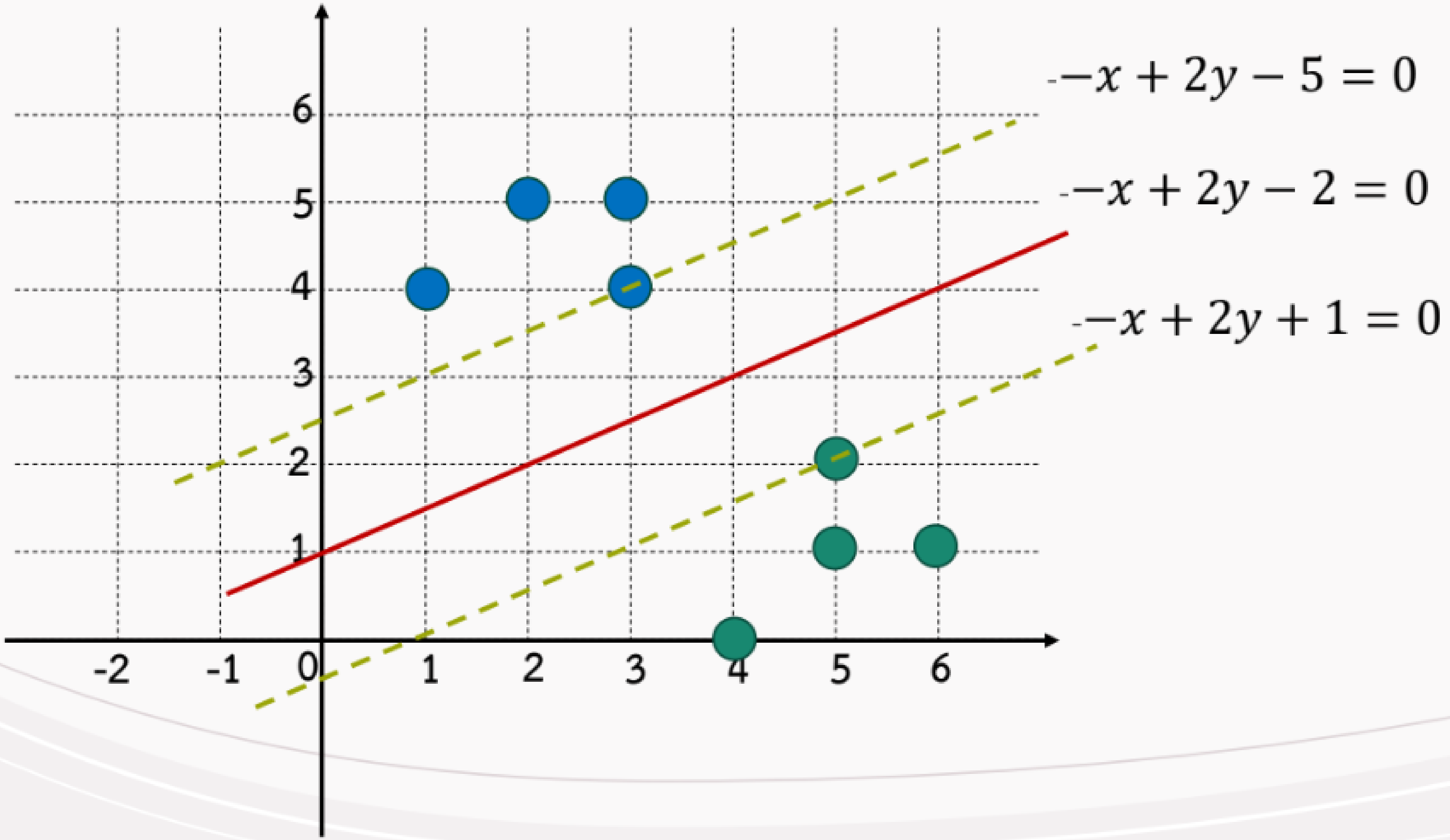
Equation of linear line



$$Ax + By + C = 0$$

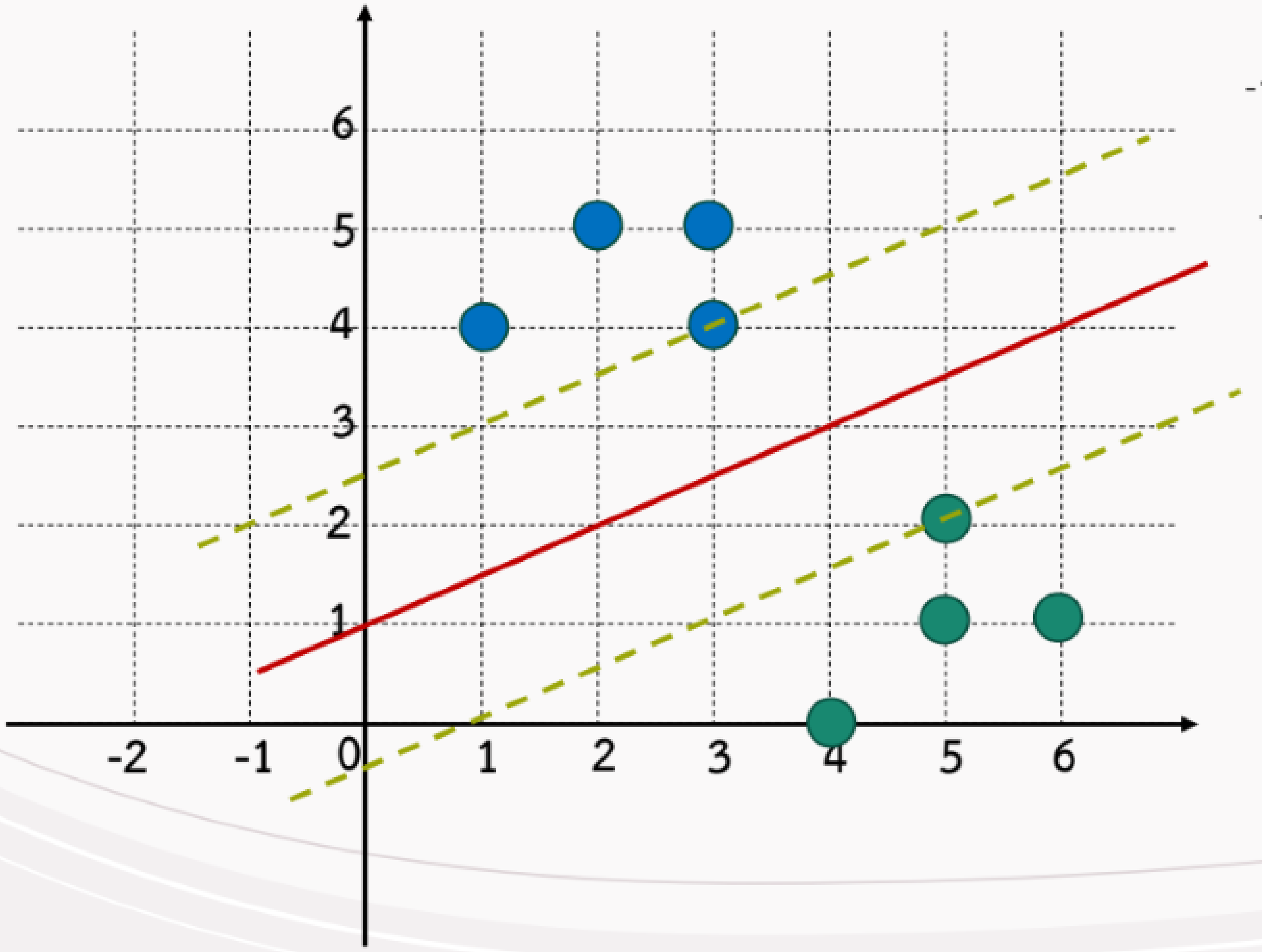
$$-x + 2y - 2 = 0$$

Idea of SVM



Idea of SVM

$$W = \begin{bmatrix} -\frac{1}{3} \\ \frac{2}{3} \end{bmatrix}, \quad \bar{x} = \begin{bmatrix} x \\ y \end{bmatrix}$$



$$-\frac{1}{3}x + \frac{2}{3}y - \frac{2}{3} = 1$$

$$-\frac{1}{3}x + \frac{2}{3}y - \frac{2}{3} = 0$$

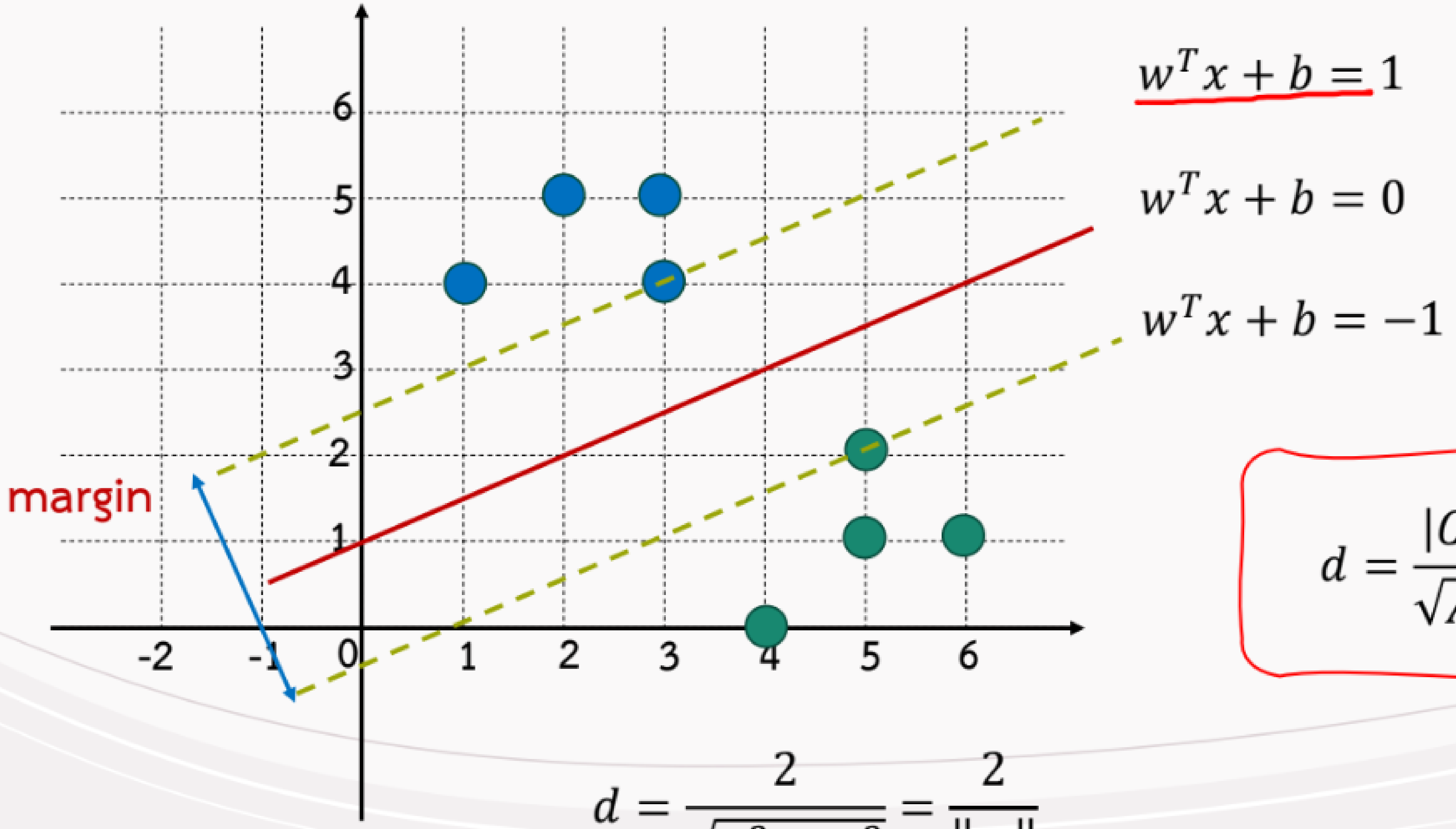
$$-\frac{1}{3}x + \frac{2}{3}y - \frac{2}{3} = -1$$

$$w^T\vec{x} + b = 0$$

$$\begin{bmatrix} -\frac{1}{3} & \frac{2}{3} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} - \frac{2}{3} = 0$$

Idea of SVM

$Ax + By + C = 0 \Rightarrow w^T\vec{x} + b = 0$

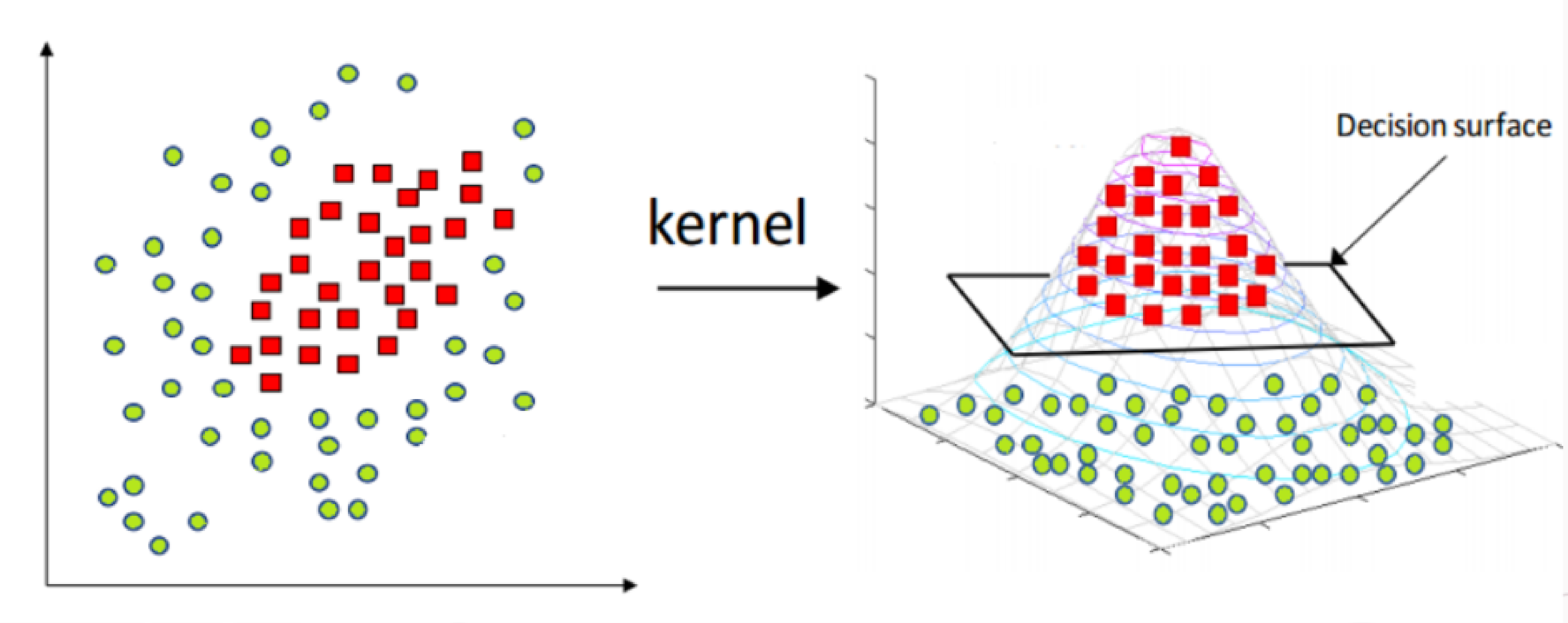


$$\boxed{d = \frac{|C_1 - C_2|}{\sqrt{A^2 + B^2}}}$$

$$d = \frac{2}{\sqrt{A^2 + B^2}} = \frac{2}{\|w\|}$$

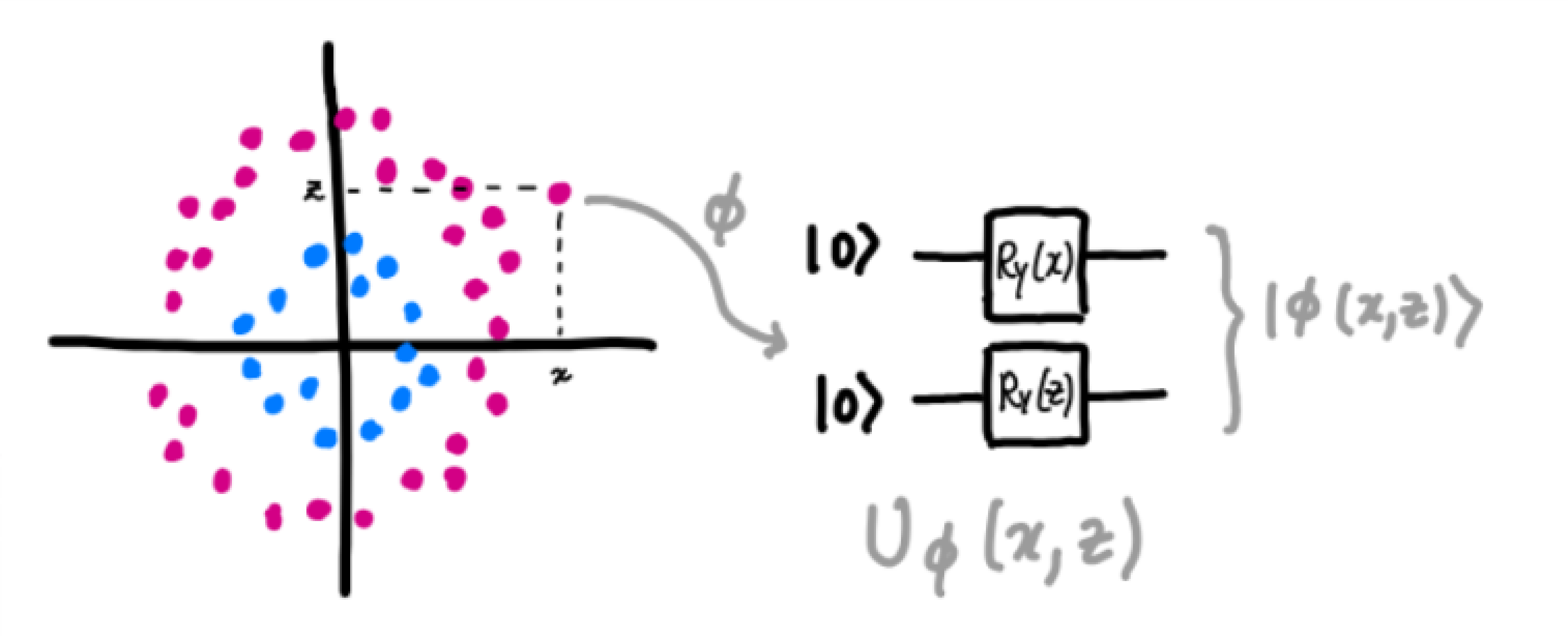
Kernel in SVM

In the case of non-linear data set, we can use the Kernel trick to classify the points.



Support Vector Machine(SVM): A Complete guide for beginners (analyticsvidhya.com)

Quantum SVM

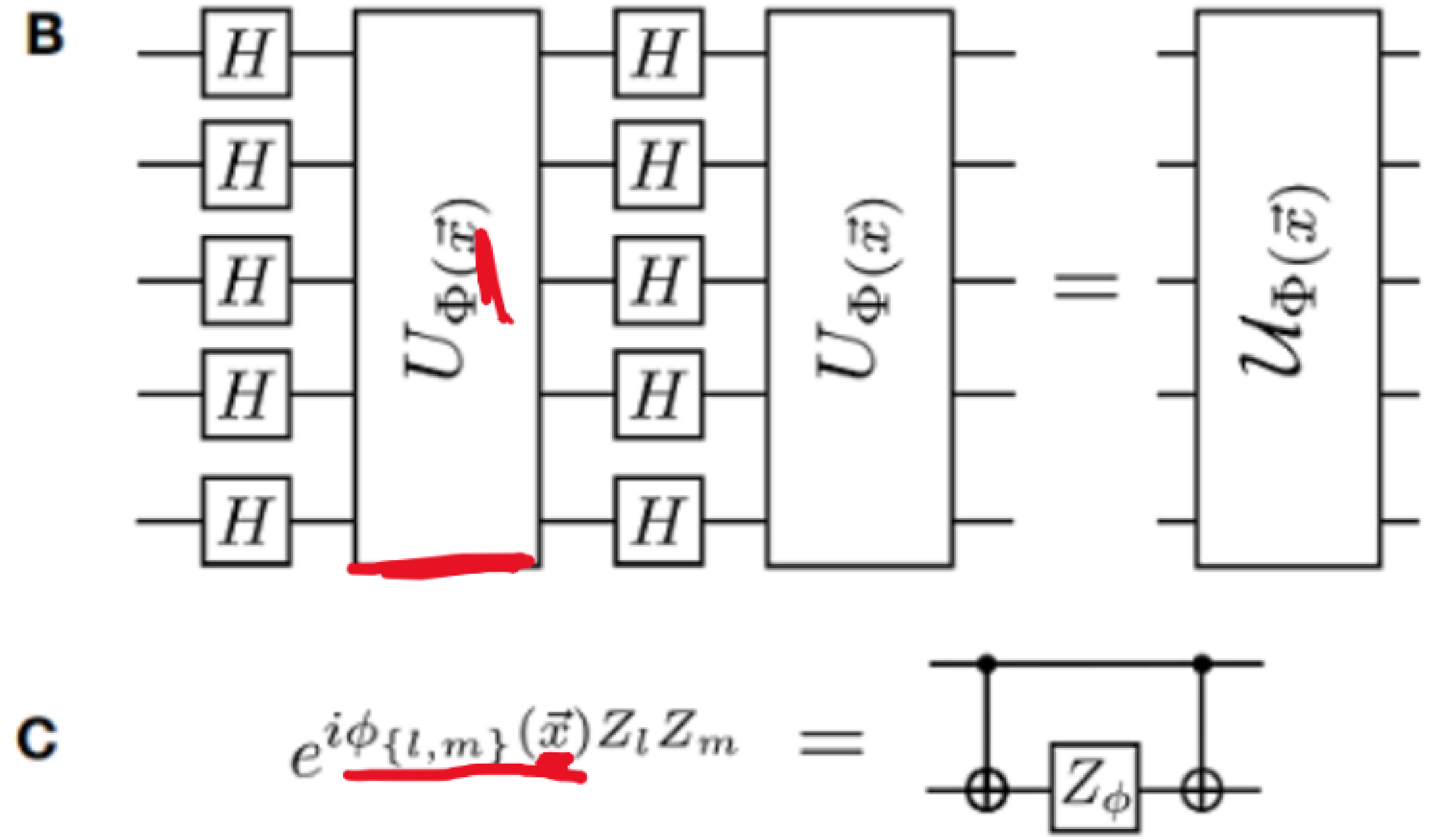


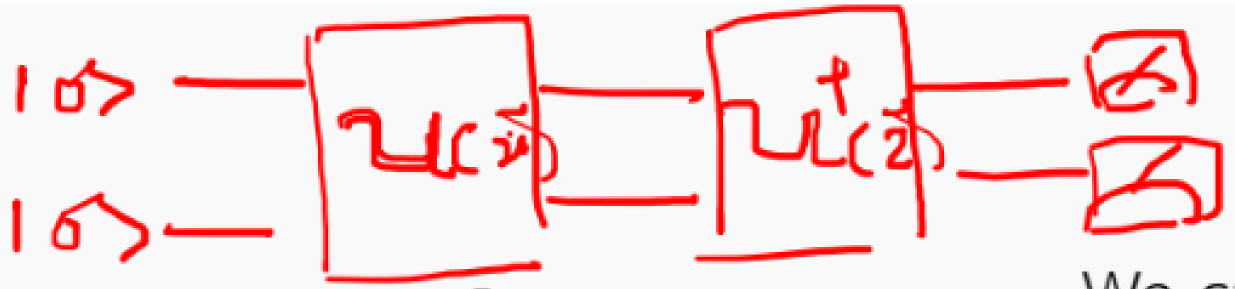
https://pennylane.ai/

We need to translate classical data points $\vec{X}$ into a quantum data $|\varphi(\vec{x})\rangle$. This can be achieved by a circuit $V(\varphi(\vec{x}))$. This stage is called ***Feature map***.

Feature Map

$$|\varphi(\vec{x})\rangle = V(\varphi(\vec{x}))|0\rangle$$



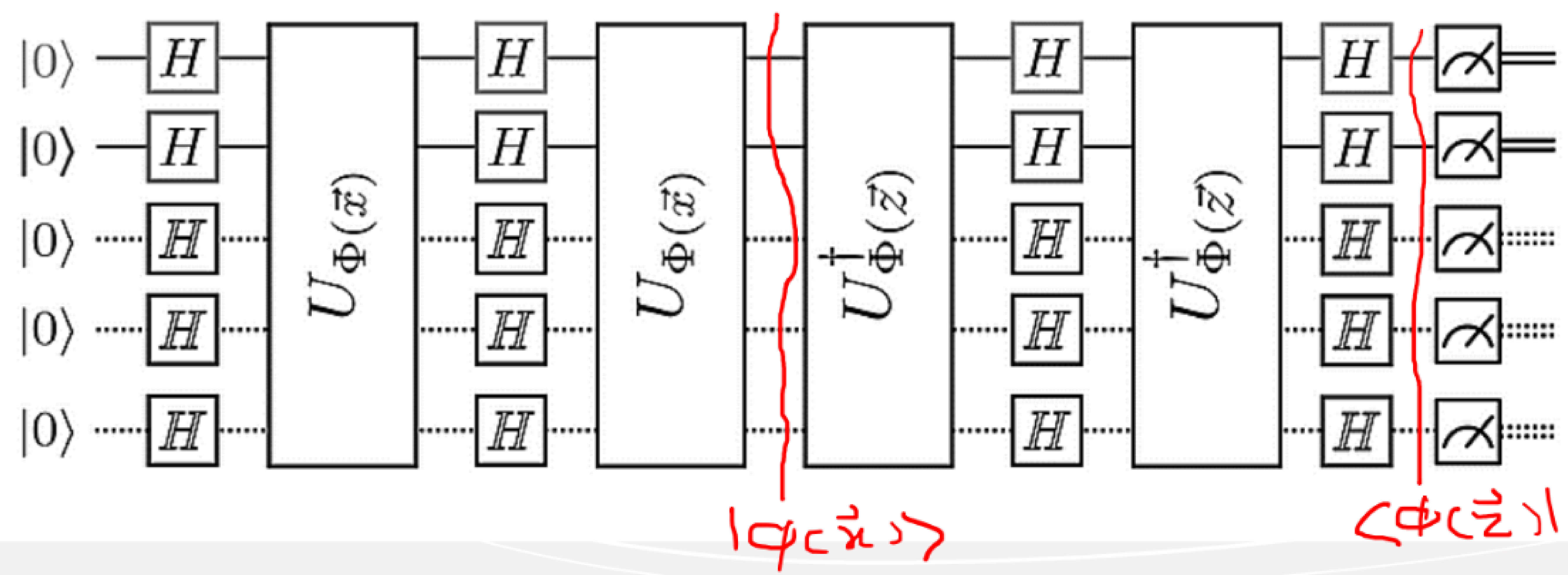


$|\psi\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \delta|11\rangle$

Quantum Kernel

We calculate the quantum Kernel to feed it into the classical SVM algorithm.

$$K(\vec{x}, \vec{z}) = |\langle\varphi(\vec{z})|\varphi(\vec{x})\rangle|^2$$



https://medium.com/@patrick.huembeli/introduction-into-quantum-support-vector-machines-727f3ccfa2b4

Coding time… again with Qiskit

https://github.com/the-scamper/intro_quantum_ml

Conclusions

- intro Quantum Computer ✓
- Qubit ✓
- 1-qubit state & 1-qubit gate ✓
- 2-qubits state & 2-qubits gate ✓
- measurement ✓
- intro machine learning ✓
- concept SVM ✓
- QSVM ✓
- Labs with Qiskit ✓


QuTE
QUANTUM TECH ENDEAVOR
QuTE: Quantum Technology Education Thailand
2.8 พัน ถูกใจ • ผู้ติดตาม 3 พัน คน
ส่งข้อความ
ถูกใจแล้ว
ค้นหา
โพสต์
เกี่ยวกับ
Mentions
รีวิว
ผู้ติดตาม
รูปภาพ
เพิ่มเติม


QUANTUM COMPUTING
MADE SIMPLE WITH
QUANTUM BLUE
Quantum Blue
99 ถูกใจ • ผู้ติดตาม 134 คน
ส่งข้อความ
ถูกใจแล้ว
ค้นหา
โพสต์
เกี่ยวกับ
Mentions
รีวิว
ผู้ติดตาม
รูปภาพ
เพิ่มเติม
แนะนำตัว
Empowering Quantum Computing knowledge sharing
เพจ · บริษัทด้านเทคโนโลยีสารสนเทศ · ศูนย์ชุมชน
quantumblue.cat@gmail.com
โพสต์
ตัวกรอง
Quantum Blue
16 มิถุนายน
บริษัทยักษ์ใหญ่เริ่มที่จะลงทุนในควอนตัมเทคโนโลยีแล้ว !