



Summer quantum computing program



June 2025
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Today

- Introduction to quantum information
 - Notebook 1 : Single qubit quantum simulator
- How to program a quantum computer?
 - Notebook 2 : Intro to PennyLane
- Next steps

Connecting to the Magic Castle (virtual machine)

1. Create your username and password on [Mokey](#)
2. Use them to connect to the [virtual machine](#)

Sign in

Username:

Password:

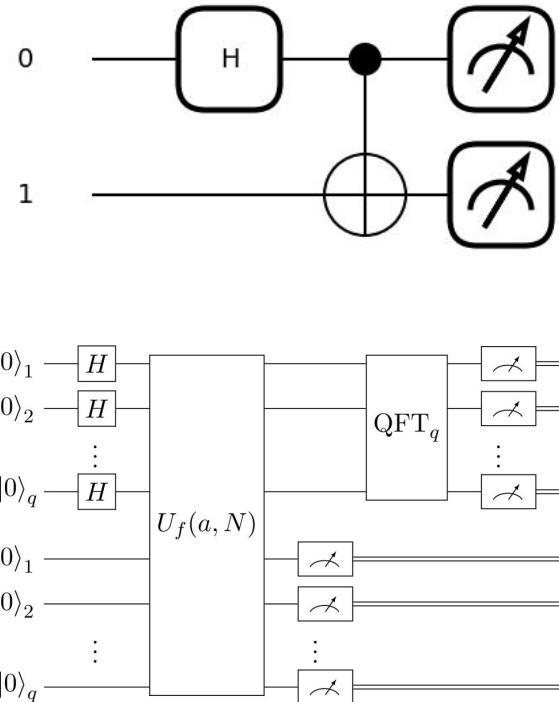
Sign In



You can save your work on the virtual machine as you work. However, **we strongly recommend that you also make regular backups** locally or on GitHub.

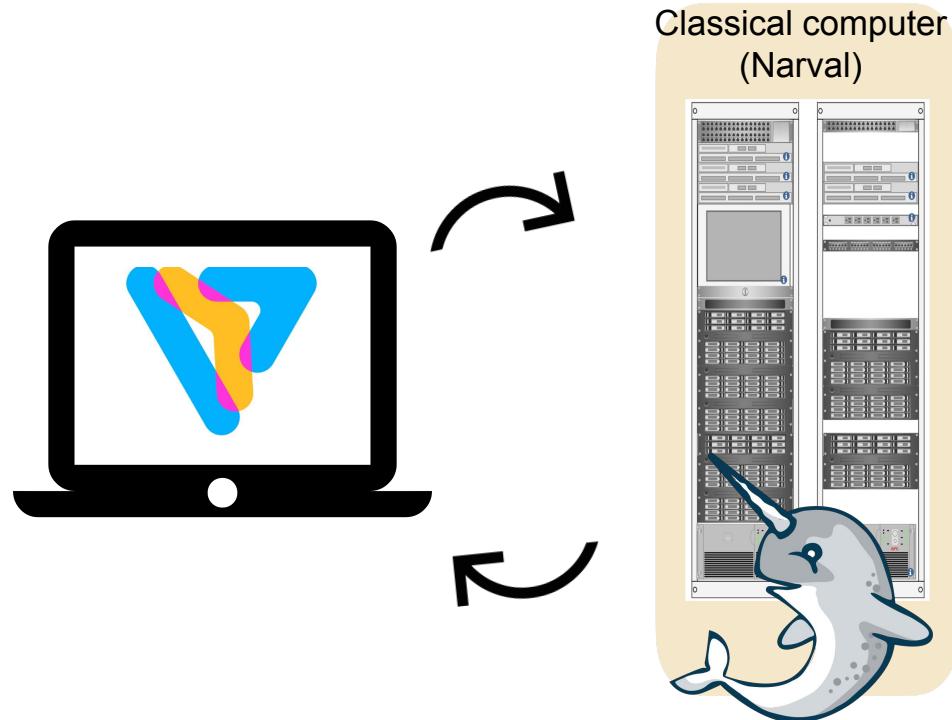
Suggested workflow

Design quantum circuits in PennyLane



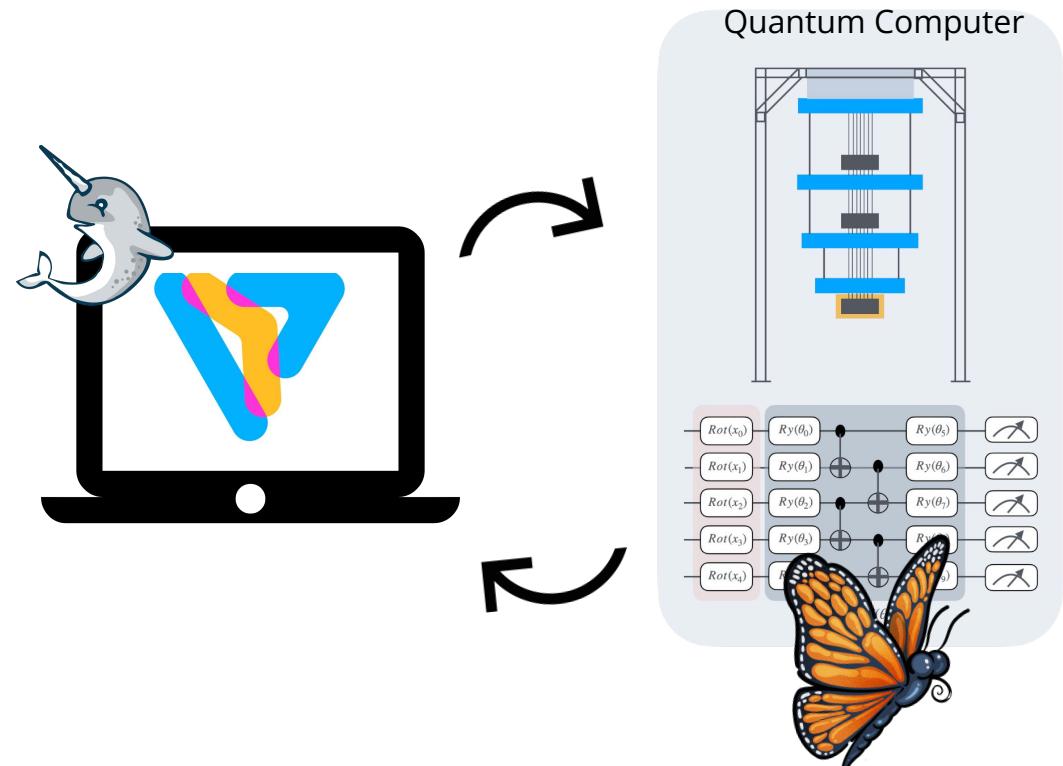
Suggested workflow

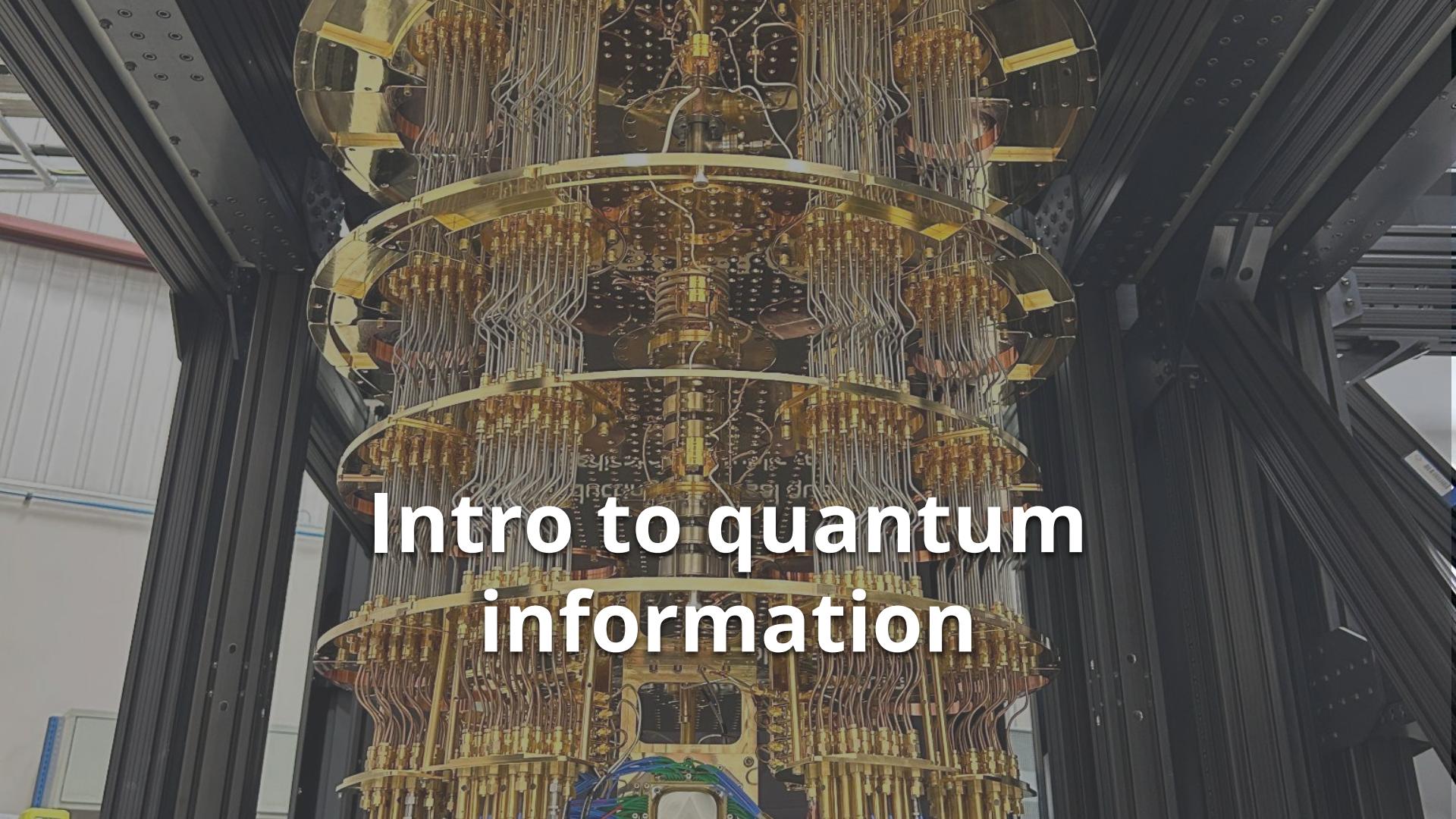
**Simulate your
quantum
circuits
on a classical
supercomputer**



Suggested workflow

**Run your
quantum
circuits
on a quantum
computer**



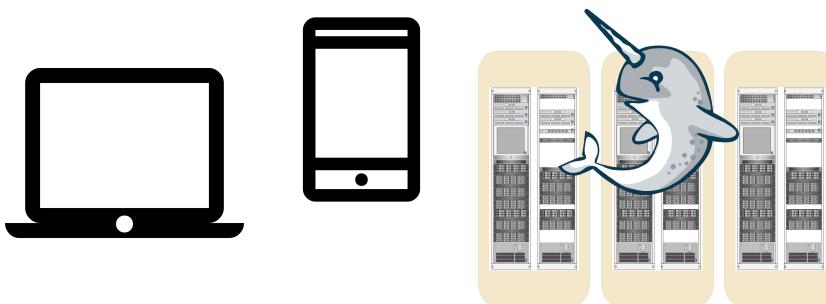
A photograph of a large-scale quantum computing system. The central component is a cylindrical assembly with multiple concentric rings of gold-colored connectors and wires. The entire apparatus is mounted within a dark, metallic frame with various ports and equipment visible on the sides.

Intro to quantum information

Overview

Classical information

- Uses binary states or **bits** (0 and 1)
- Output is deterministic
- Laptops, cell phones, computing clusters etc.



Quantum information

- Uses quantum bits or **qubits**
- Depend on the properties of quantum mechanics : superposition, interference and entanglement
- Output is probabilistic
- MonarQ



Qubit : the mathematical object

Qubits are the physical realization of a two-level quantum system, which stores and processes quantum information.

Computational basis

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

Mathematically, a qubit is a vector in a complex vector space. It can be visualized on the Bloch sphere.

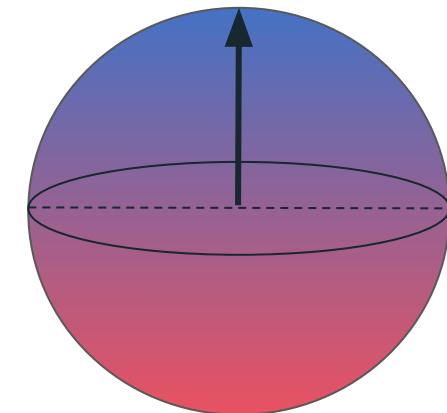
0



1

Two **classical**
bits

$|0\rangle$



One **quantum** bit
(qubit)

Qubit : the mathematical object

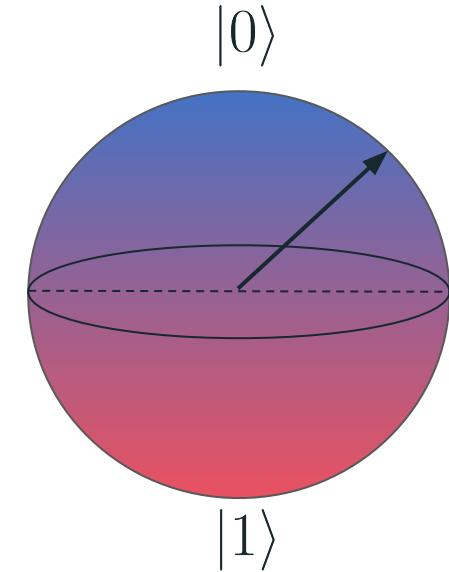
Superposition

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \text{ with } |\alpha|^2 + |\beta|^2 = 1$$

A superposition is a linear combination of basis states like $|0\rangle$ and $|1\rangle$



Two
classical
bits



One **quantum** bit
(qubit)

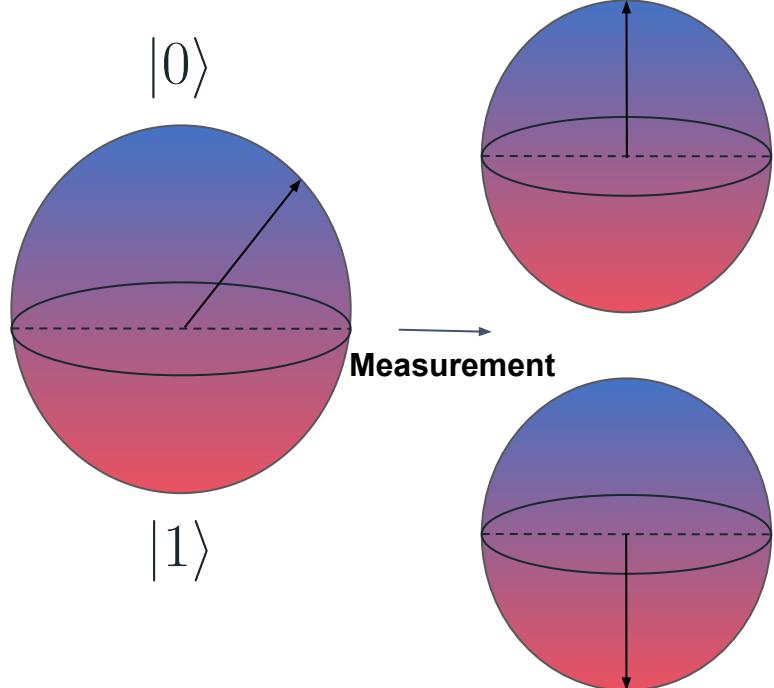
Qubit : the mathematical object

Probabilistic output at measurement

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \quad \text{with} \quad |\alpha|^2 + |\beta|^2 = 1$$

$$P(|0\rangle) = |\alpha|^2 = \alpha^* \alpha$$

$$P(|1\rangle) = |\beta|^2 = \beta^* \beta$$



Qubit : the mathematical object

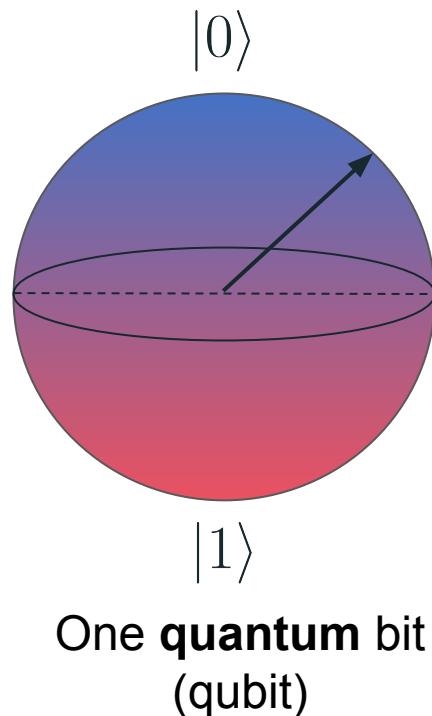
Interference

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \text{ with } |\alpha|^2 + |\beta|^2 = 1$$

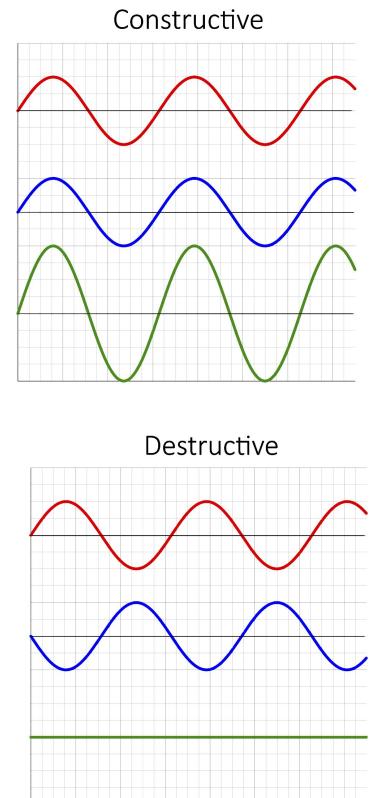
$$P(|0\rangle) = |\alpha|^2$$

$$P(|1\rangle) = |\beta|^2$$

Amplitudes and probabilities can be manipulated with constructive and destructive interference.



One **quantum bit**
(qubit)

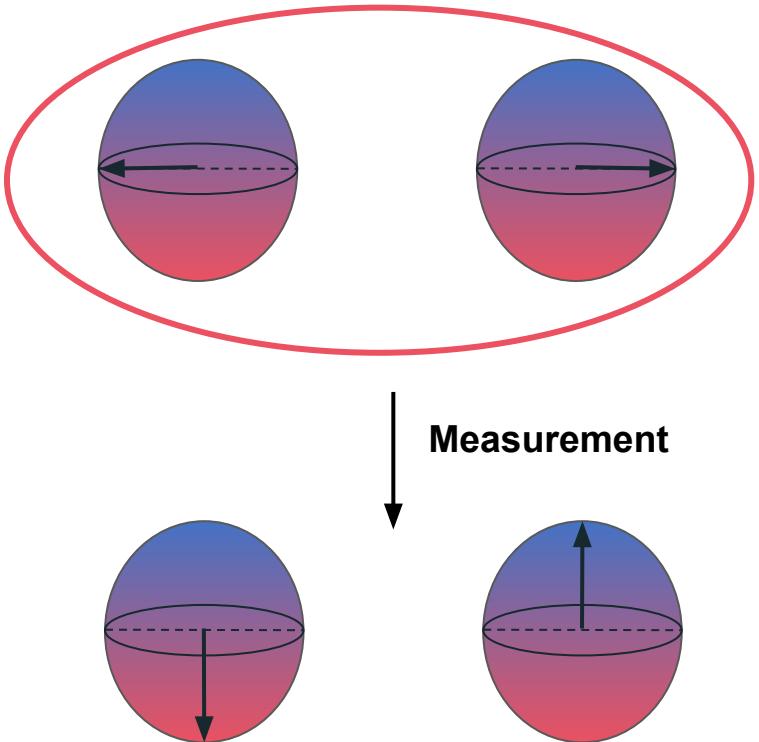


Qubit : the mathematical object

Entanglement

Entangled qubits are correlated. Measurement of one modifies the measurement of the others.

There is no equivalent in classical mechanics.

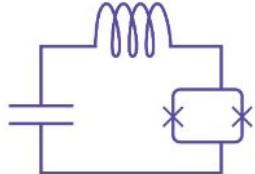




Qubit : the physical object

Atoms		Electrons			Photons
Trapped ions 	Cold atoms 	Annealing 	Superconducting 	Topological 	Photons
 IONQ QUANTINUUM	 IQuEra> Computing Inc. Pasqal	D:wave	 		 XANADU PsiQuantum

Superconducting



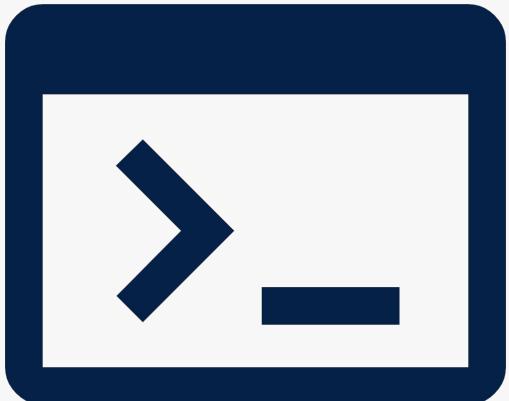
IBM
amazon
Google
ANYON
IQM
Nord Quantique



MonarQ's qubits are **transmons** made from superconducting material operating at extremely **low temperatures** and manipulated by **microwave pulses**.



Coding break



Notebook 1 :
Building a quantum simulator

Notebook 1 cheat sheet

1. Qubits can be in a **superposition state**

- $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ with $|\alpha|^2 + |\beta|^2 = 1$
- Represented by a vector in a complex vector space

2. Dirac notation

- A **ket** $|\psi\rangle$ is a column vector and its associated **bra** $\langle\psi|$ is a row vector obtained by taking the complex conjugate transpose.

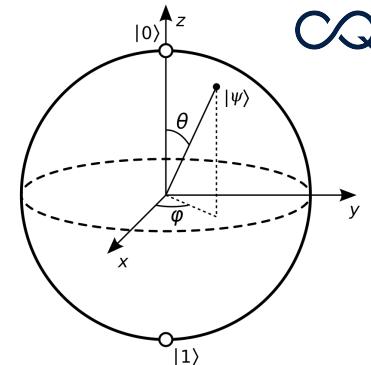
3. Bloch sphere

- **Visual representation of a qubit** as a vector on a sphere with θ and ϕ as coordinates for the state : $|\psi\rangle = \cos\left(\frac{\theta}{2}\right)|0\rangle + e^{i\phi}\sin\left(\frac{\theta}{2}\right)|1\rangle$

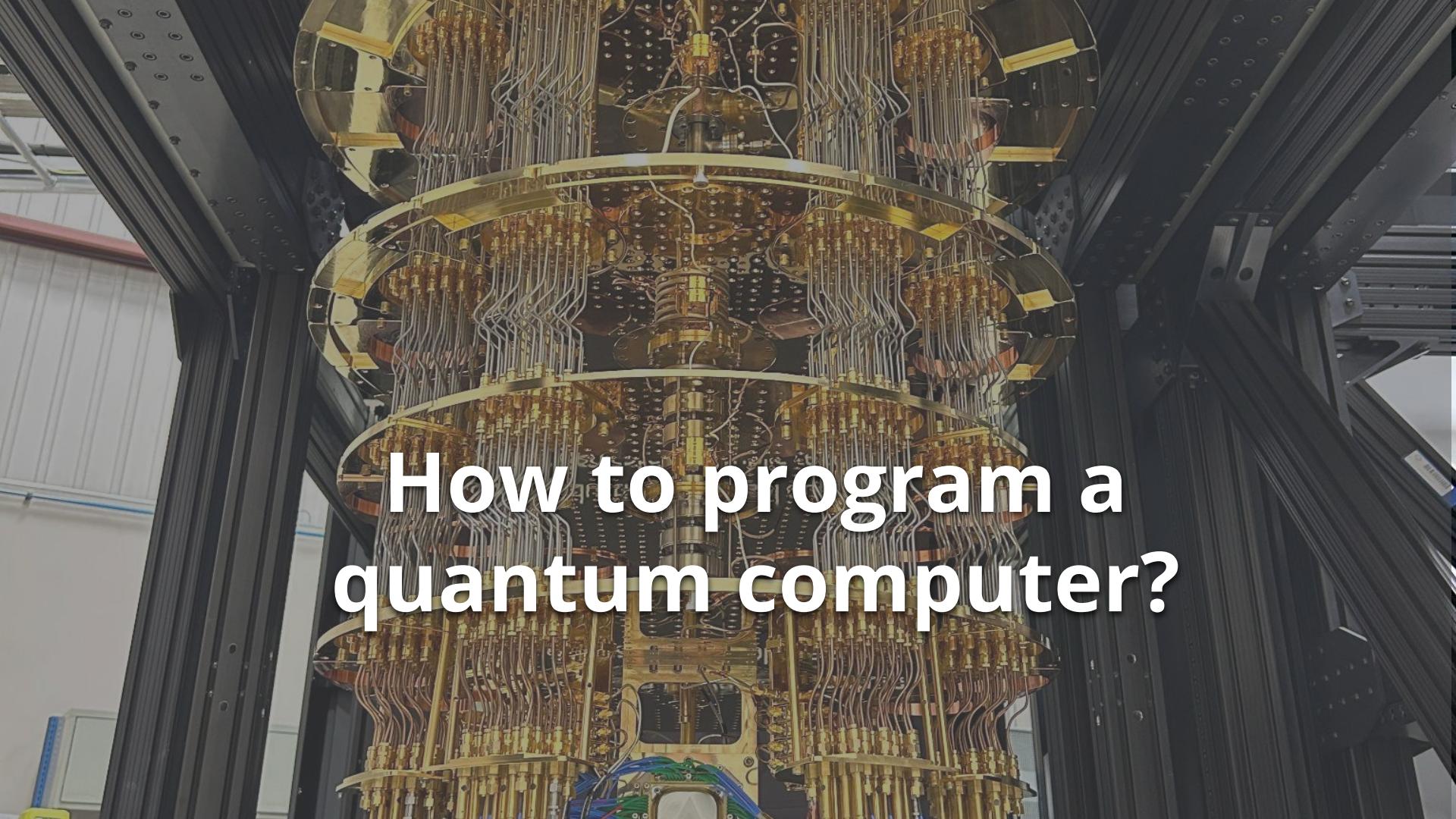
4. Quantum **gates** are **unitary matrices** and act on qubits like **rotations** on the Bloch sphere.

5. A **quantum circuit** is a sequence of unitary transformations (gates) applied to an initial state.

- $|\psi_{\text{final}}\rangle = U_n \cdots U_2 U_1 |\psi_{\text{initial}}\rangle$
- **Measurement** gives **probabilistic** results based on the final state of the qubit



∞

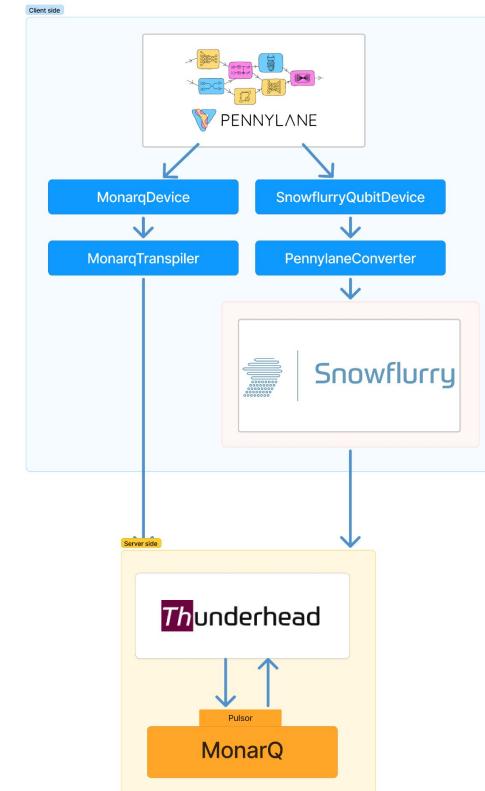
A photograph of a complex quantum computing system. It features a large, cylindrical central component with numerous gold-colored wires and connectors extending from its top and bottom. This central unit is surrounded by several concentric metal rings and a complex network of wires. The entire apparatus is housed within a dark, metallic frame, likely a vacuum chamber or cryostat. The background shows some industrial equipment and a white wall.

How to program a
quantum computer?

Quantum software development kits

- **PennyLane**
 - Developed in Python by Xanadu
 - Interface directly with MonarQ
- **Qiskit**
 - Developed in Python by IBM
 - Qiskit-calculquebec plugin in development
- **Snowflurry**
 - Developed in Julia by Anyon Systems
 - Interface directly with MonarQ

write circuits and more

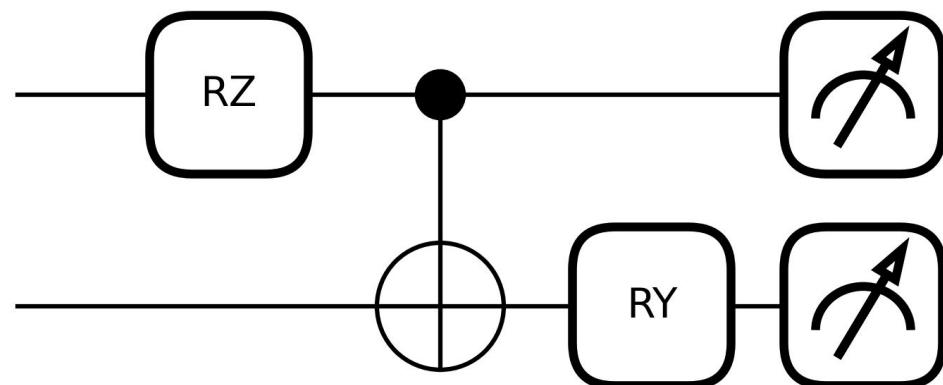


Quantum circuits

```
dev = qml.device('default.qubit', wires = 2)
@qml.qnode(dev) # qnode decorator
def quantum_function(x, y):
    qml.RZ(x, wires=0)
    qml.CNOT(wires=[0,1])
    qml.RY(y, wires=1)
    return qml.state()
```



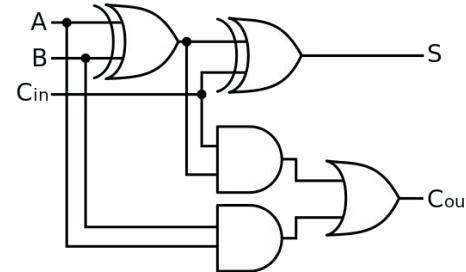
PENNYLANE



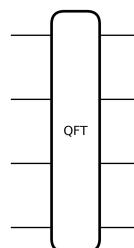
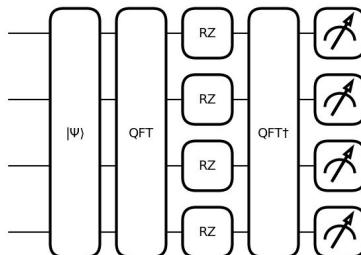
Quantum circuits

Classical computers also use circuits, but we do not generally think about these explicitly.

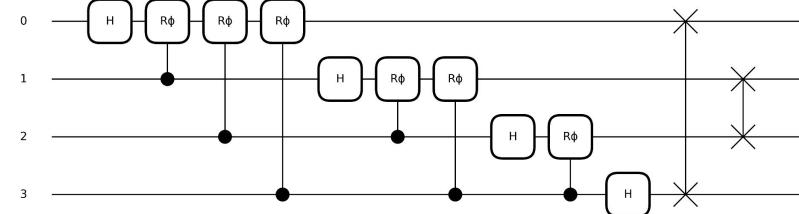
- **Classical** boolean circuit for addition



- **Quantum** circuit for addition

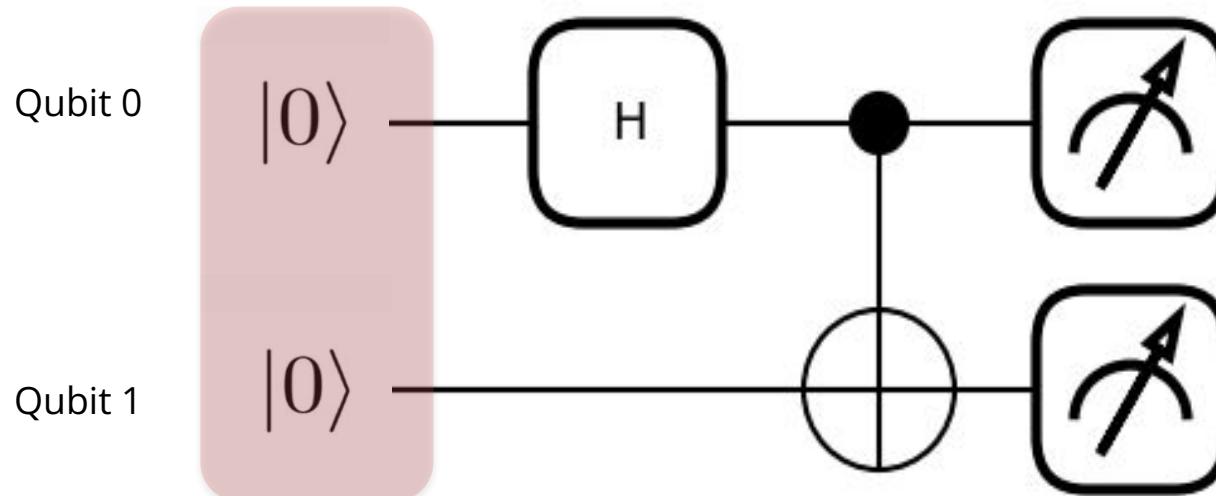


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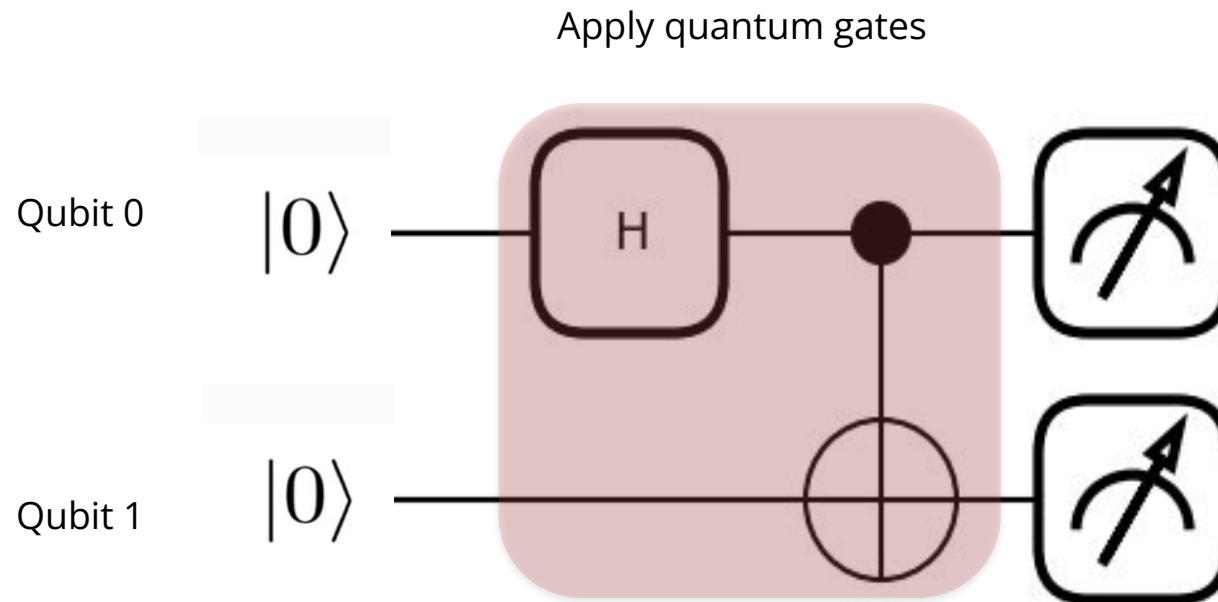


Key components of a quantum circuit

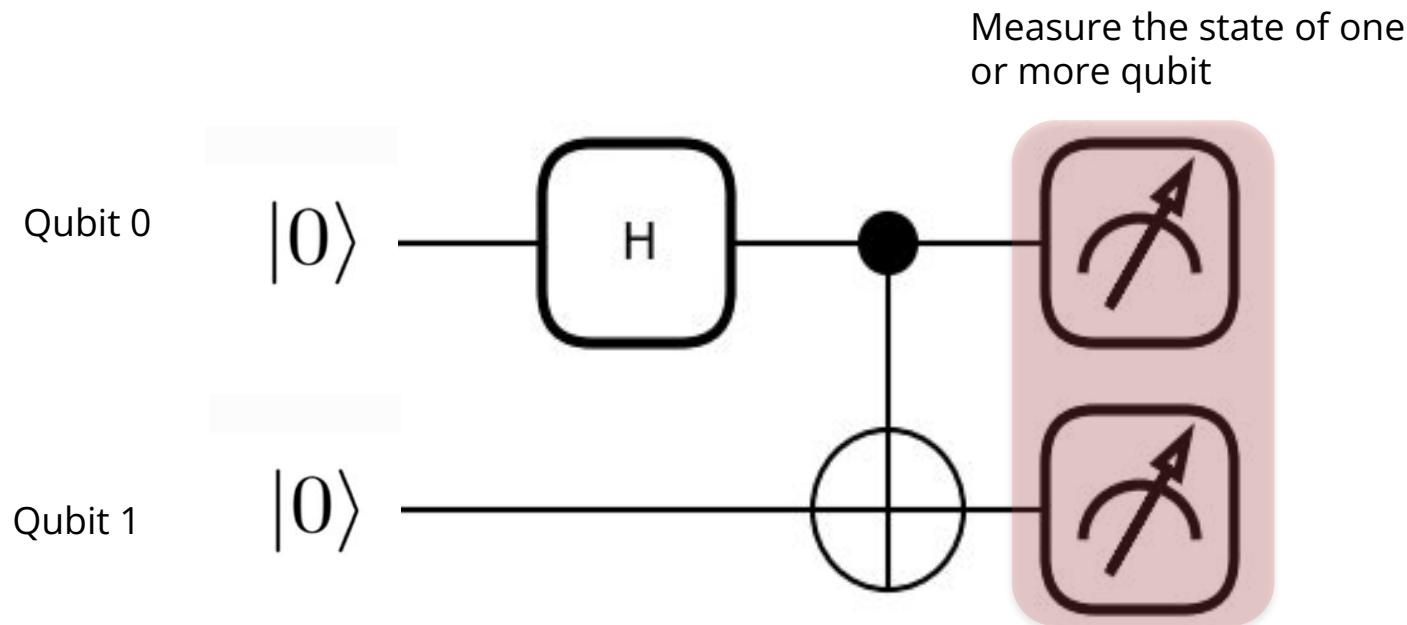
Each qubit is initialized
to state 0 by default



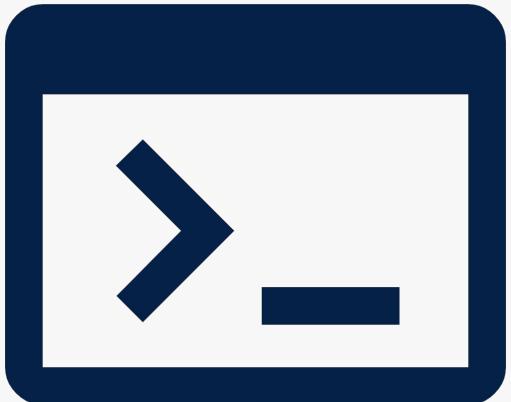
Key components of a quantum circuit



Key components of a quantum circuit



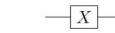
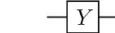
Coding break



**Notebook 2 :
PennyLane Basics**

Notebook 2 cheat sheet

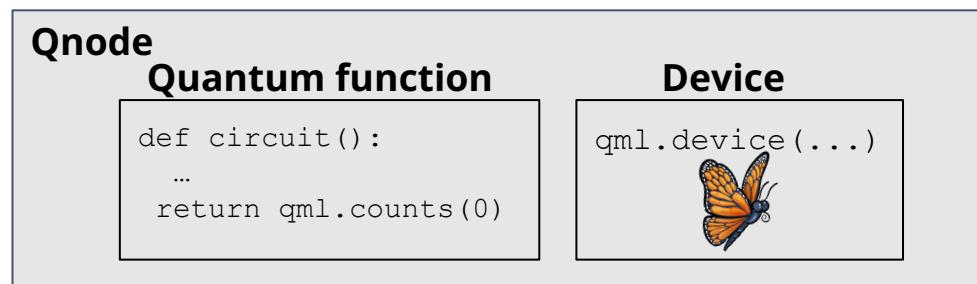
- Quantum circuits are composed of gates**

Gate	Circuit Element	Matrix Representation	Action on Basis States
Hadamard Gate H		$\frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$	$H 0\rangle = \frac{1}{\sqrt{2}}(0\rangle + 1\rangle)$ $H 1\rangle = \frac{1}{\sqrt{2}}(0\rangle - 1\rangle)$
Pauli-X Gate X		$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$	$X 0\rangle = 1\rangle$ $X 1\rangle = 0\rangle$
Pauli-Y Gate Y		$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$	$Y 0\rangle = i 1\rangle$ $Y 1\rangle = -i 0\rangle$
Pauli-Z Gate Z		$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$	$Z 0\rangle = 0\rangle$ $Z 1\rangle = - 1\rangle$
CNOT Gate		$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	$CNOT 00\rangle = 00\rangle$ $CNOT 01\rangle = 01\rangle$ $CNOT 10\rangle = 11\rangle$ $CNOT 11\rangle = 10\rangle$

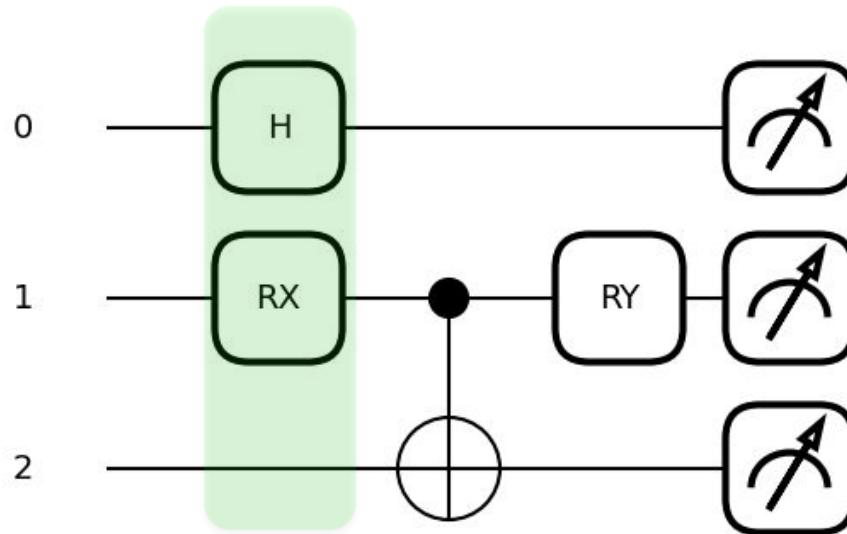
- Quantum circuits must return a measurement**

(`qml.state`, `qml.expval`, `qml.probs`, `qml.counts`)

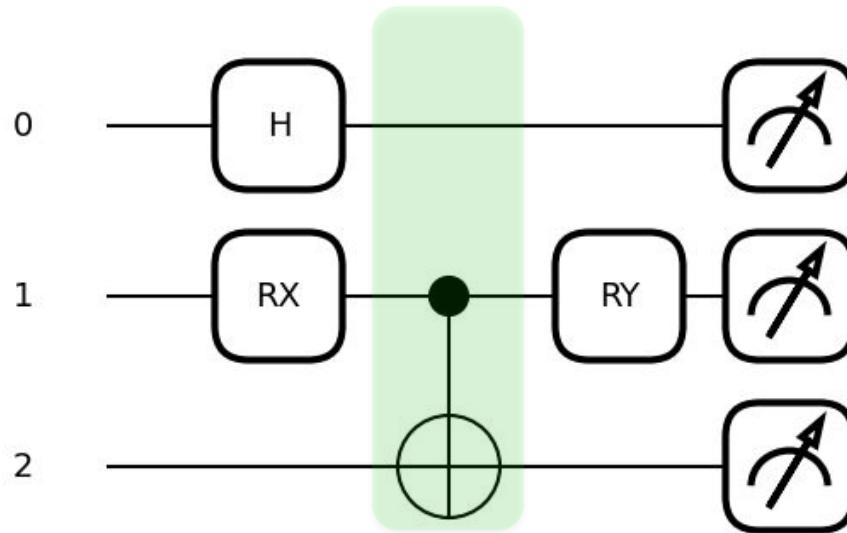
- Link a circuit and a device together with a Qnode**



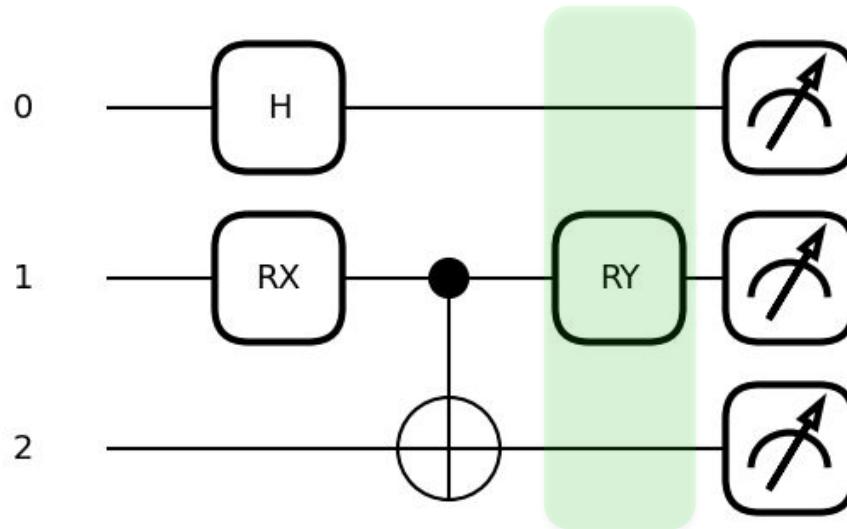
Circuit depth



Circuit depth

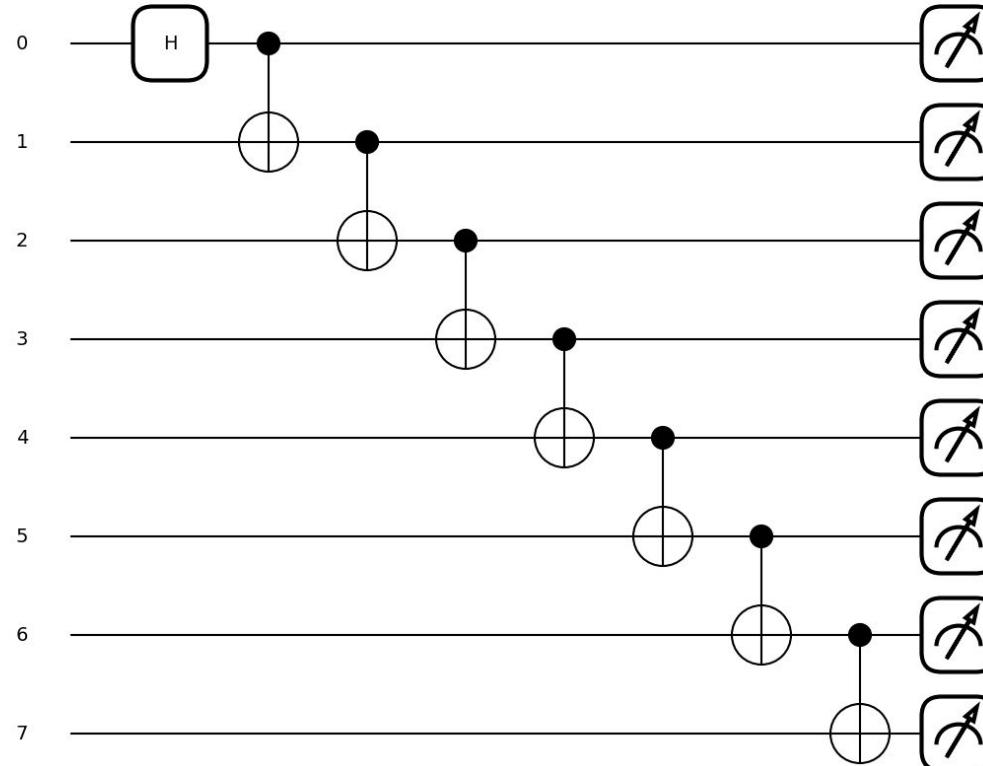


Circuit depth



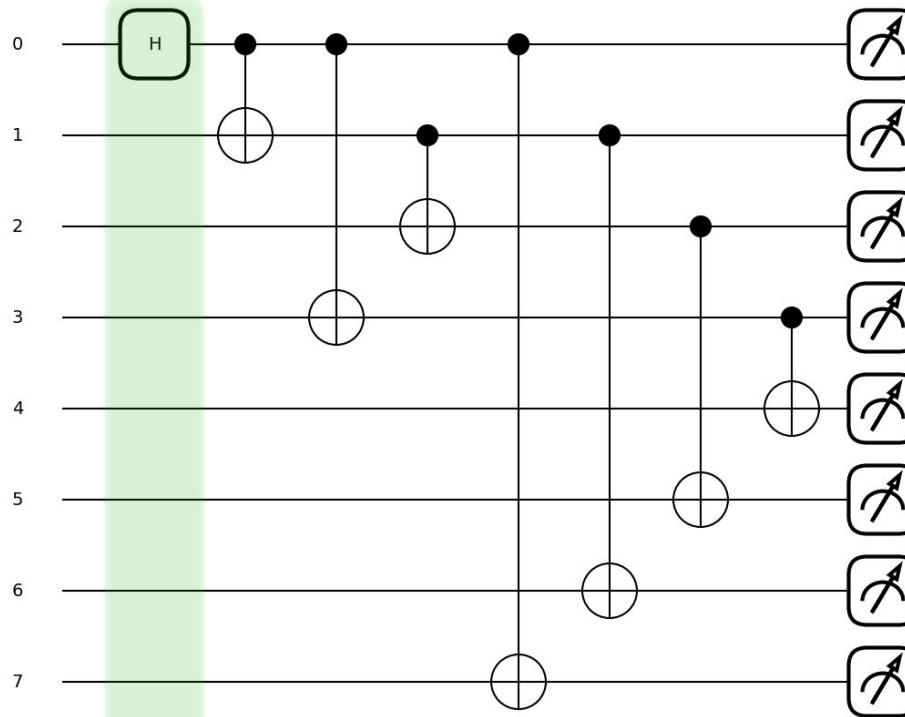
The depth of this circuit is 3.

Circuit depth

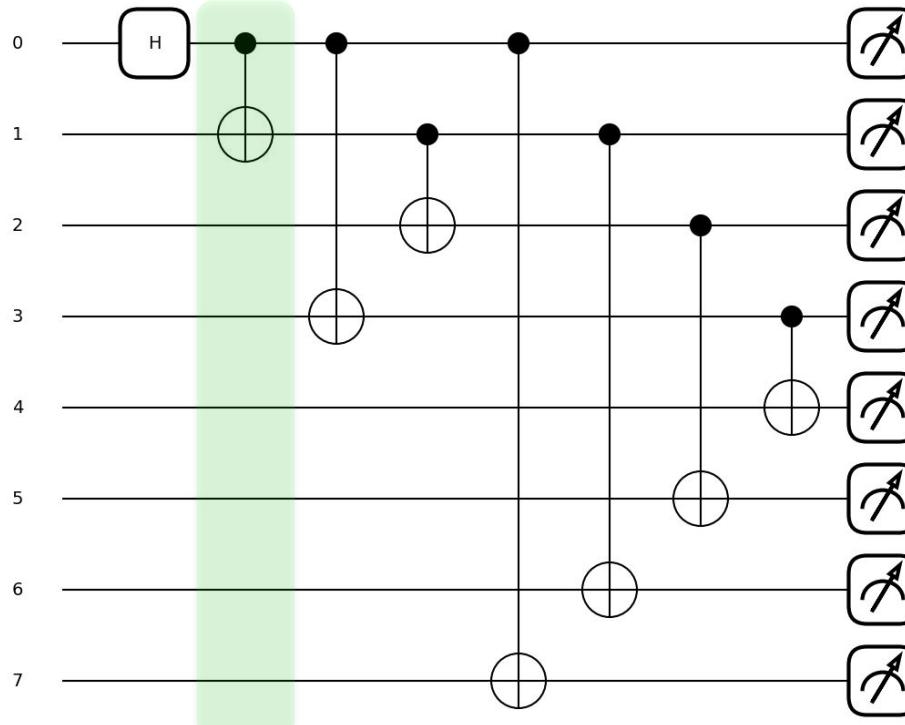


What is the depth of this circuit?

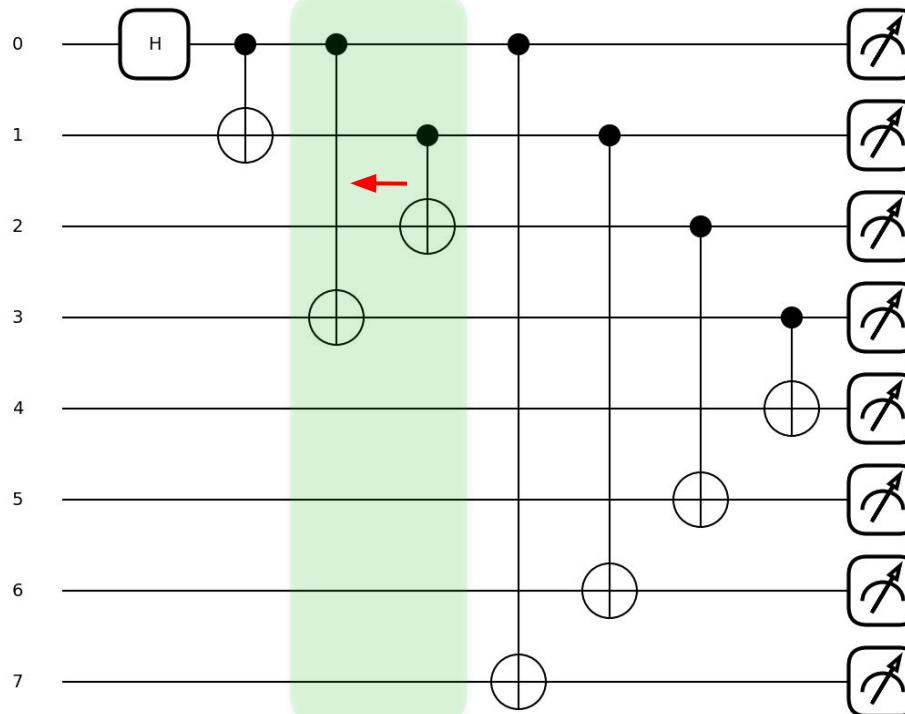
Circuit depth



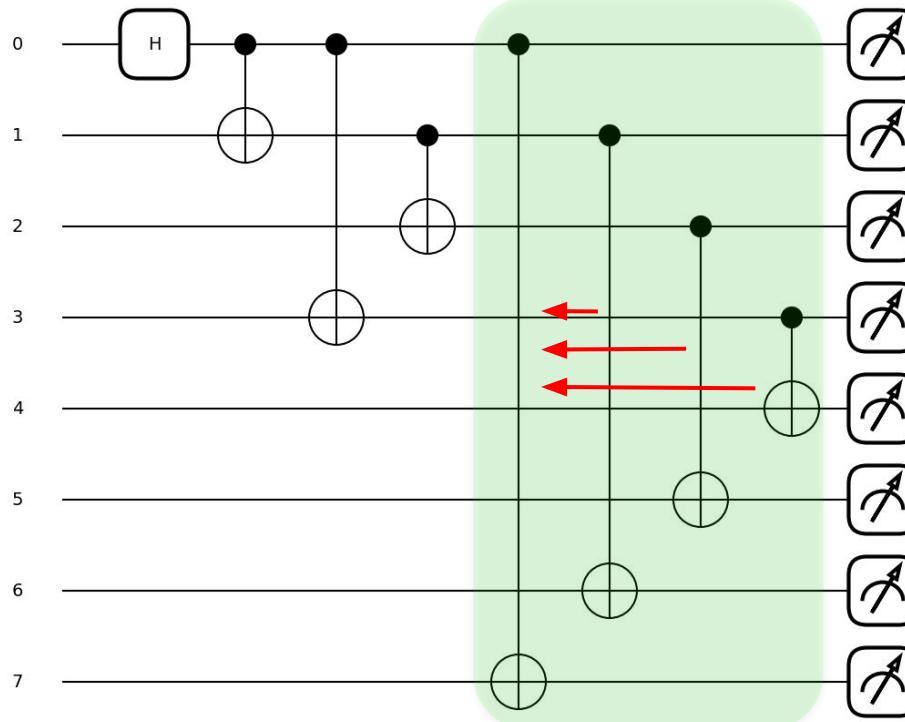
Circuit depth



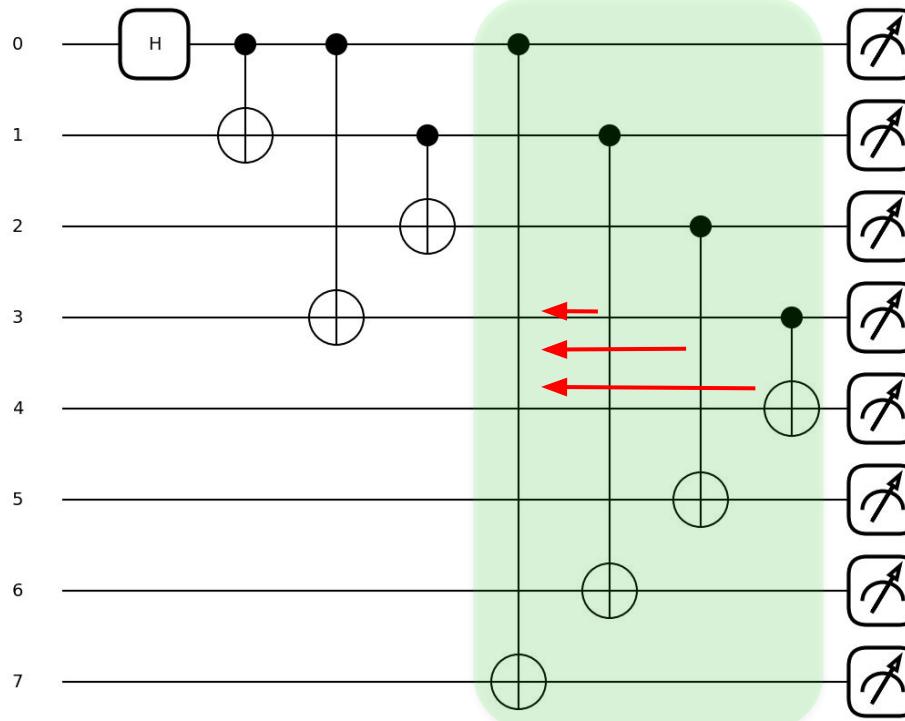
Circuit depth



Circuit depth



Circuit depth



The depth of this circuit is 4.



Key Dates

*Dates tentative

June 10	11:00 - 12:30	Workshop : Intro to Quantum Information and PennyLane
June 17 to 20	TBD	Individual Project Consultation : 30-minute 1-on-1 meetings to discuss project scope
June 26	TBD	Workshop : Running jobs on MonarQ and the Calculquebec-Pennylane plugin
July 17	10:00 - 11:00	Group Roundtable : Brief project update
August 21	17:00 - 19:00	Final project presentations and MonarQ visit

Next steps

- Literature review
 - Have similar projects been done?
 - Is this feasible on a NISQ computer ?
 - How many qubits? What is the circuit depth?
- Recreate results or a toy problem from a recent article with PennyLane or Qiskit
- Schedule your one-on-one!

