SENG 457/CSC 557

Lab 2: Qiskit and PennyLane

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To-do list for today

- Get started with Qiskit
- Get started with PennyLane
- Sign the attendance sheet!

Activity 1: Hello Circuit

- Reduce the number of quantum registers to 1
- Reduce the number of classical registers to 1

Note that we can manipulate the number of registers by also going to Edit > Manage Registers

- What do we see under:
    - Probabilities: ?
    - Q-Sphere: ?
    - Statevector: ?

Activity 2: Flip the state

- Transform the state of `q[0]` from $|0\rangle$ to $|1\rangle$
- What gate(s) would we apply?
- What do we see under:
  - Probabilities: ?
  - Q-Sphere: ?
  - Statevector: ?

Activity 3: Superposition and Grouping

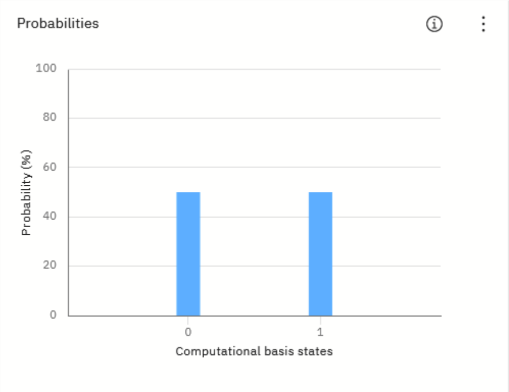
- Transform the state of `q[0]` to the equal superposition state $\frac{|0\rangle - |1\rangle}{\sqrt{2}}$
- Group the gates involved and call it the "MinusOp"

- What gate(s) would we apply?
- What do we see under:
  - Probabilities: ?
  - Q-Sphere: ?
  - Statevector: ?

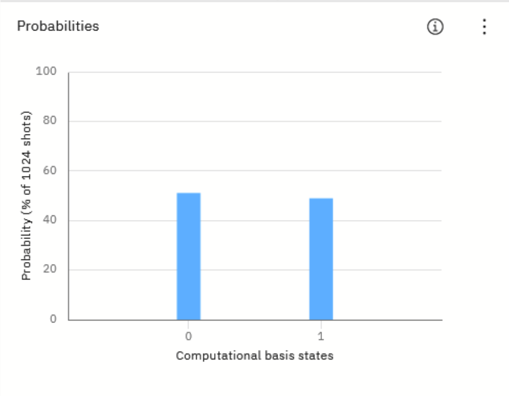
Activity 4: Measurement

- Append a measurement operation to `q[0]` which was in the same state as in Activity 3, i.e., $\frac{|0\rangle - |1\rangle}{\sqrt{2}}$
- What do we see under:
    - Probabilities: ?
    - Q-Sphere: ?
    - Statevector: ?

A note on probabilities and measurement



(a) Without measurement (analytical calculation)

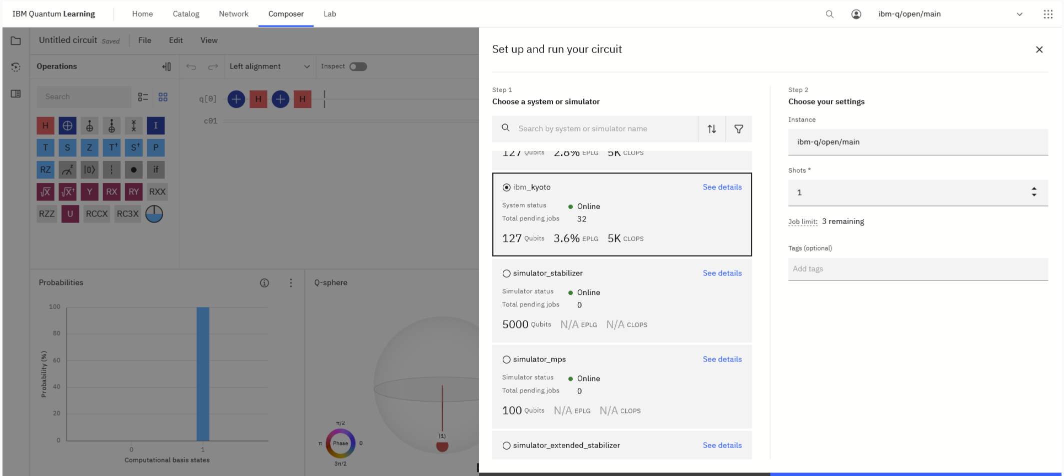


(b) With measurement (out of 1024 shots)

Figure 1: In Figure 1a, probabilities shown are $|\alpha|^2$ and $|\beta|^2$. Figure 1b shows results when the circuit is run 1024 times, which is uneven due to "shot noise".

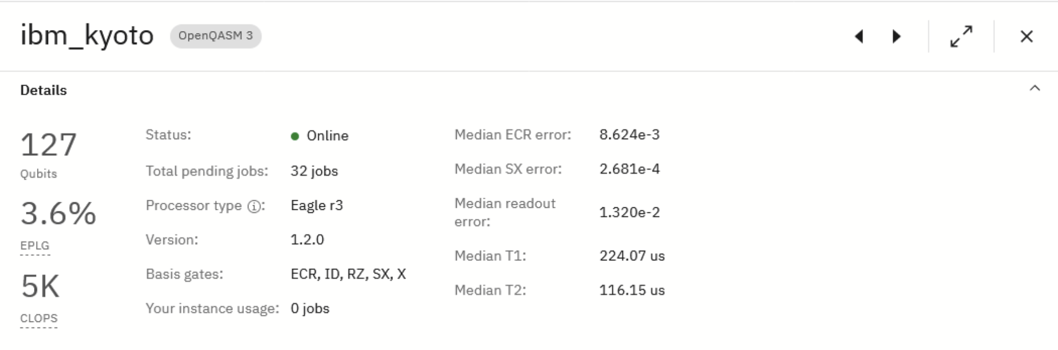
Features: Running on actual quantum machines

- Click on "Setup and Run" on the right top corner in the composer to see available machines to run your quantum experiments on.



IBM Kyoto

- EPLG: Error Per Layered Gate
- CLOPS: Circuit Layer Operations Per Second



Two good articles: 1-How we measure quantum quality and speed
2- Three Metrics for Quantum Computing Performance: Scale, Quality and Speed

The Bloch Sphere

- The Bloch sphere is a geometric representation used in quantum mechanics to visualize the state of a single qubit, which is the basic unit of quantum information.
- Let's navigate to: https://javafxpert.github.io/grok-bloch/

Q-Sphere

- The q-sphere represents the state of a system of one or more qubits (the Bloch sphere can represent only one qubit)
- The quantum amplitude is given as $\sqrt{p_k}e^{i\phi_k}$
- $\sqrt{p_k}$ is the magnitude of the amplitude
- $e^{i\phi_k}$ is the **phase** and is calculated as

$$e^{i\phi_k} = \cos(\phi_k) + i\sin(\phi_k)$$

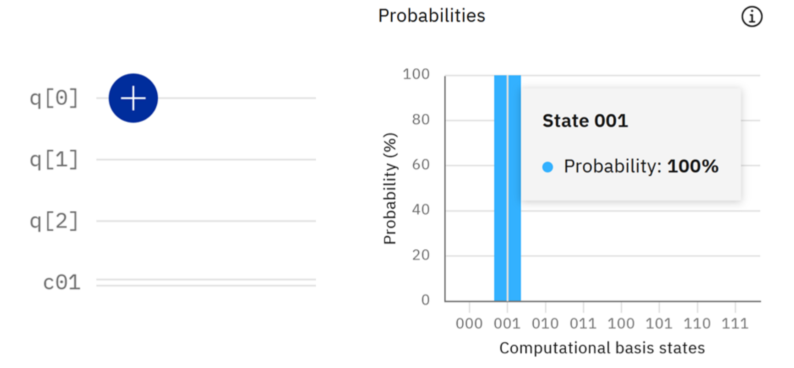
- For example, given a state $\frac{|0\rangle - |1\rangle}{\sqrt{2}}$, the magnitude of amplitude of the $|1\rangle$ state is $\frac{1}{\sqrt{2}}$ and the phase is calculated as $e^{i\pi} = -1$

The Qiskit Pattern

The four steps to writing a quantum program using Qiskit Patterns are:

- Map the problem to a quantum-native format.
- Optimize the circuits and operators.
- Run the AerSimulator for simulation or IBM Runtime for execution on QPU.
- Analyze the results.

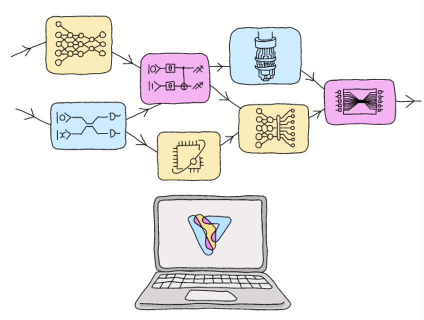
Qiskit Bit Ordering (Right to Left)



PennyLane

QNode

- Represents a quantum node in the hybrid computational graph.
- A quantum node contains a quantum function (corresponding to a variational circuit) and the computational device it is executed on.
- The QNode calls the quantum function to construct a QuantumTape instance representing the quantum circuit.



Device[1]

This defines the device that the quantum circuit should be simulated/run on

- ‘`default.qubit`’: A simple state simulator of qubit-based quantum circuit architectures.
- ‘`default.mixed`’: A mixed-state simulator of qubit-based quantum circuit architectures.
- ‘`lightning.qubit`’: A more performant state simulator of qubit-based quantum circuit architectures written in C++.

Device

Quantum circuit creation: The program creates a quantum circuit using the qml.qnode decorator and the dev device object.

```
dev = qml.device('default.qubit', wires=1, shots=1024)
```

[1] https://docs.pennylane.ai/en/stable/code/api/pennylane.device.html

Measurement Statistics

For any quantum node, the following values can be returned:

- Statevector
- Probabilities
- Expectation Values
- Samples

Sample Program: Returning Probabilities

```
[16]: dev = qml.device('default.qubit', wires=1, shots=1024)

      @qml.qnode(dev)
      def circuit():
          qml.Hadamard(wires=0)
          return qml.probs(wires=0)
```

```
[17]: print("Probabilities:", circuit())
```

```
Probabilities: [0.47949219 0.52050781]
```

Sample Program: Returning the Statevector

- Note that for returning a Statevector, you should not pass the shots parameter in the device

```
[13]: dev = qml.device('default.qubit', wires=1)

      @qml.qnode(dev)
      def circuit():
          qml.Hadamard(wires=0)
          return qml.state()

[14]: print("State:", circuit())

      State: [0.70710678+0.j 0.70710678+0.j]
```