QILIMANJARO
QUANTUM · TECH

Qilimanjaro's Quantum as a Service

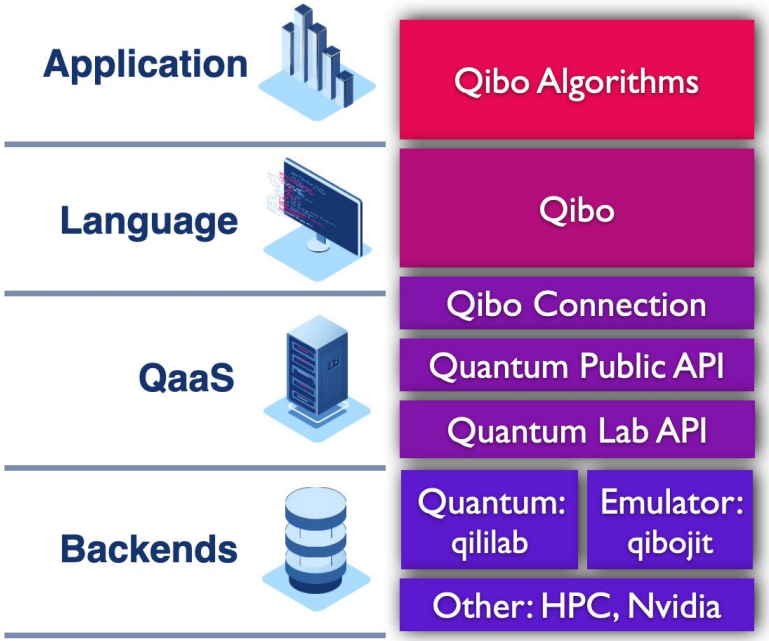
An HPC use case

09/05/2024

www.qilimanjaro.tech

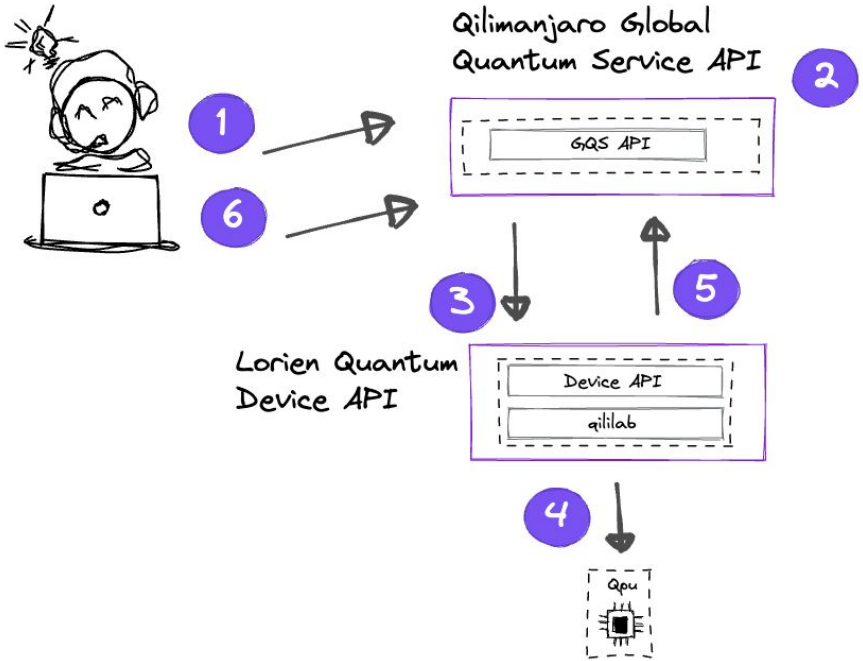
INDEX

1.0 Qilimanjaro's QaaS: The Stack



- **Key components**
  - A **user interface** (python, web, etc), for the users to interact with our services.
  - A **cloud-based publicly available API**, that interfaces with all the services we may offer.
  - A series of **centers of execution**, some of them being labs with QPUs, and others being powerful classical computing machines.

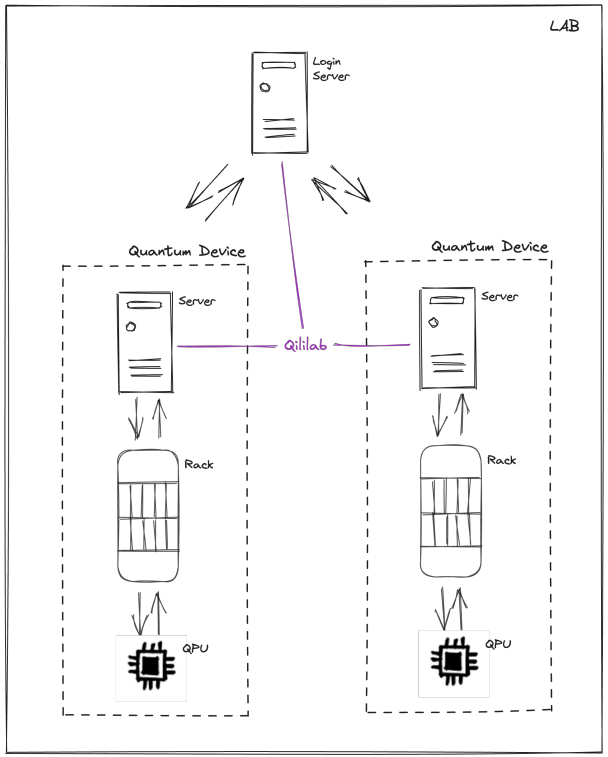
1.1 Job travel



Typical workflow

1. User submits a **job** and gets a **`job_id`**.
2. Our **Public API** receives and processes the request.
3. Request is **relayed to** the corresponding device.
4. **QPU** or simulator performs the due operations.
5. **Results** are sent to our Public API.
6. User can **retrieve the results** using their **`job_id`**.

1.2 Job execution



Typical workflow

1. Connects to our **login node**.

2. User writes a python notebook using **`qililab`**.
   - `qililab` allows to **describe** the experiments.
   - `qililab` distributes the execution to the required **slurm partition**.
   - `qililab` implements the logic for talking to the **control hardware**.

3. **Results** are saved in users home and recovered by qililab.

2.0 Slurm Integration: WHY?

Use case: *Qilimanjaro HW Engineers want to run a quantum experiment*

Constraint: *Only one job can run at a time in our QPUs.*

Before:

1. Use **`Qiboconnection`** to block remote executions.
2. Use Slack to coordinate with other HW engineers
3. SSH to Rack Server –e.g, Compute Node – and use **`Qililab`**

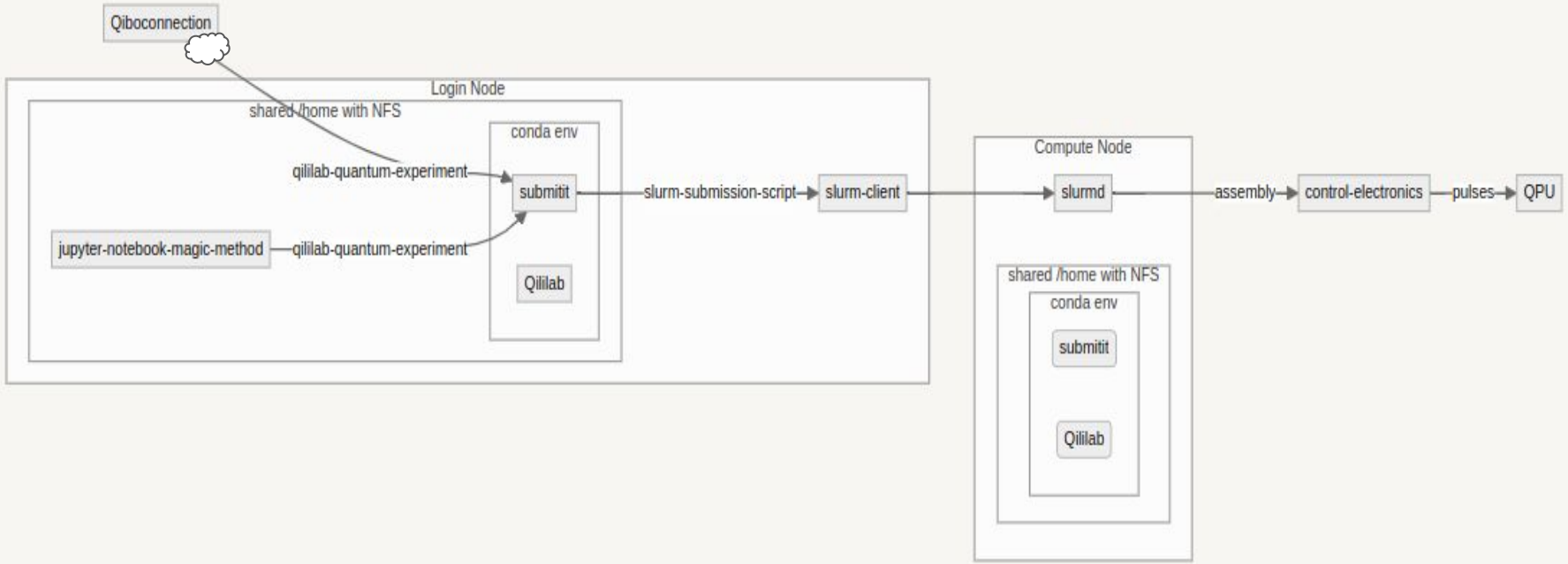
After:

1. SSH to Login Node and use **`Qililab`**

→ **DRAMATIC increase in QPUs availability both for external and internal users.**

2.1 Slurm Integration, HOW?

Python-Slurm interface: submitit



2.2 Slurm Integration, NEXT STEPS: HPC-QC integration

Main motivation: **Hybrid jobs** - e.g, Variational Quantum Algorithms and Tensor Networks

- NISQ era: quantum resources are very scarce
- Use QPUs only where they provide an advantage

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How to split classical and quantum computation between different nodes, within the same job?

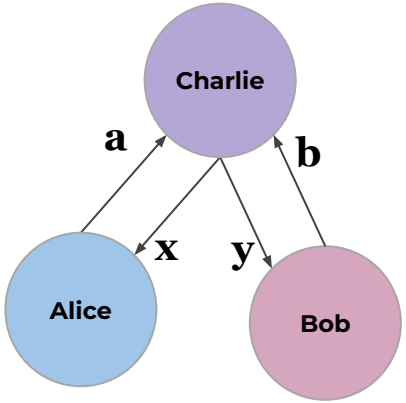
Current status: exploring different approaches under collaboration with HPCNow!

03. Practical example: CHSH game

code here!

- Demonstration of quantum effects, classically impossible
  - Non-local correlations in quantum states (entanglement)

- C sends x,y to A, B
  - x and y are chosen uniformly
- A, B send a, b to C
- A, B win iff $x \wedge y = a \oplus b$



What strategy can Alice and Bob chose in order to have the best chance of winning?

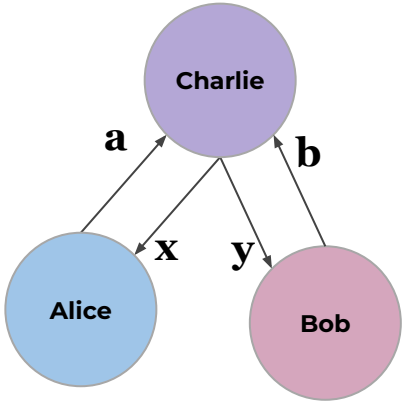
03. Practical example: CHSH game - classical

code here!

- A, B win iff $x \wedge y = a \oplus b$

x	y	x ∧ y
0	0	0
0	1	0
1	0	0
1	1	1

a	b	a ⊕ b
0	0	0
0	1	1
1	0	1
1	1	0

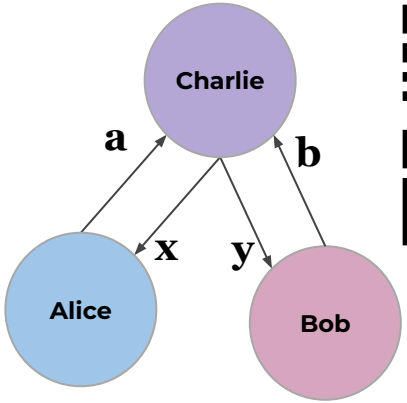


- Best strategy if A, B always chose 0
  - A, B have at most ¾ chance of winning

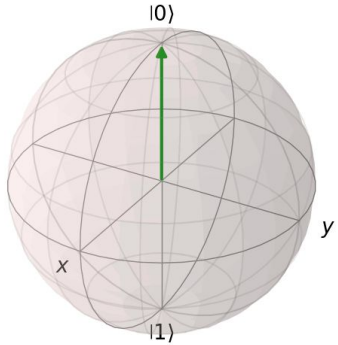
03. Practical example: CHSH game - quantum

code here!

- A, B win iff $x \wedge y = a \oplus b$



- A, B prior share a **bell state** $|\Psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle \otimes |\downarrow\rangle - |\downarrow\rangle \otimes |\uparrow\rangle$
  - These are entangled, so there is a correlation between the measurement obtained by A, B
- A, B measure their bell state in different basis, depending on whether they receive 0 or 1
  - If A receives 0: measure in the Z basis, returns 0 or 1 if measure 0 or 1
  - If A receives 1: measure in the X basis, returns 0 or 1 if measure + or -
  - If B receives 0: measure in the (X+Z) basis, returns 0 or 1 if measure 0 or 1
  - If B receives 1: measure in the (X-Z) basis, returns 0 or 1 if measure 0 or 1



A, B have at most **$\cos^2(\pi/8)$** chance of winning

03. Practical example: CHSH game

code here!

- Mathematical formulation (J.S. Bell, 1971)

$$|E(a,b) - E(a,b') + E(a',b) + E(a',b')| \leq \begin{cases} 2 & \text{classical} \\ 2\sqrt{2} & \text{quantum} \end{cases}$$

- Further reading:
  https://plato.stanford.edu/entries/bell-theorem/
  https://en.wikipedia.org/wiki/CHSH_inequality

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Thank you!