NeIC Workshop 01 June 2022

Quantum Computing and Programming

Jake Muff - LUMI

CSC – IT Center for Science

jake.muff@csc.fi

ICT Solutions for Brilliant Minds

CSC

Quantum computing activities at CSC

Enabling the uptake of quantum computing among our customer base

- Quantum computing courses and webinars, public outreach

Quantum computers will *merge* with supercomputers, not replace them

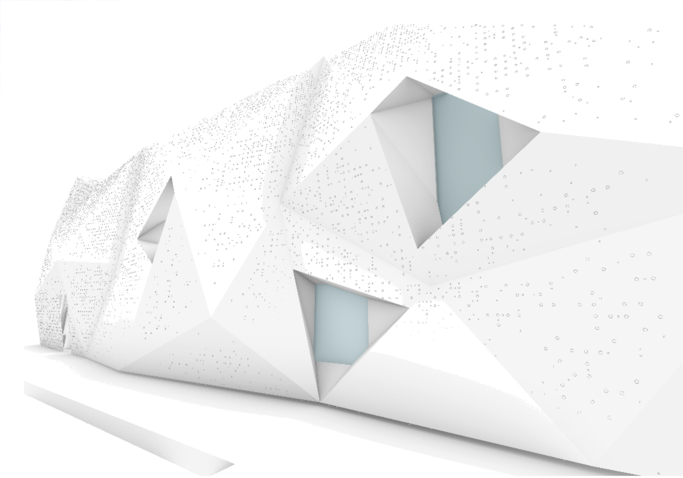
- Combine classical high-performance computing and quantum computing:
  “best of both worlds”

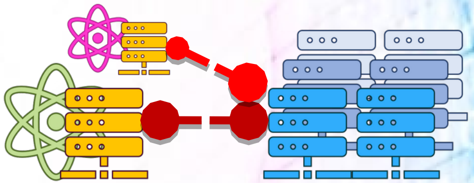
LUMI is an ideal platform for hybrid HPC+QC

- pre-exascale (550+ PFLOPS) supercomputer

In the process of integrating several quantum computers to LUMI

- Important to provide our users with a broad selection of different quantum resources, as soon as possible
- Kvasi, the Atos QLM 30+ qubit emulator available since 2020





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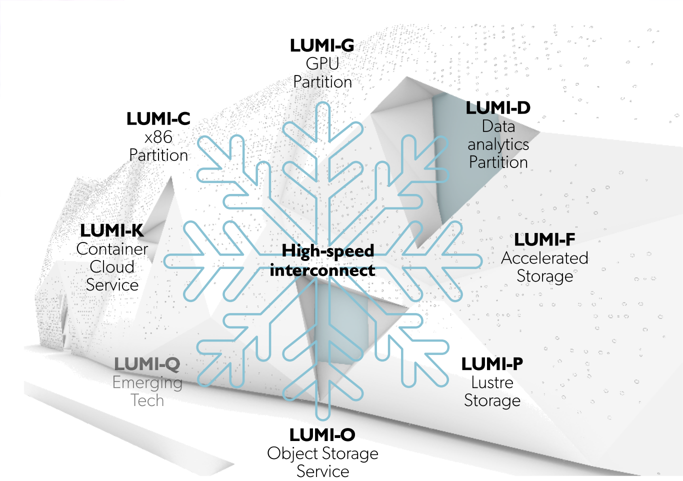
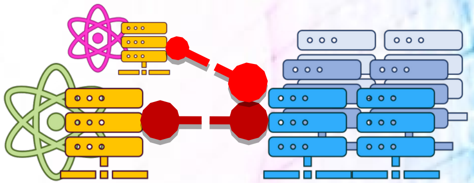
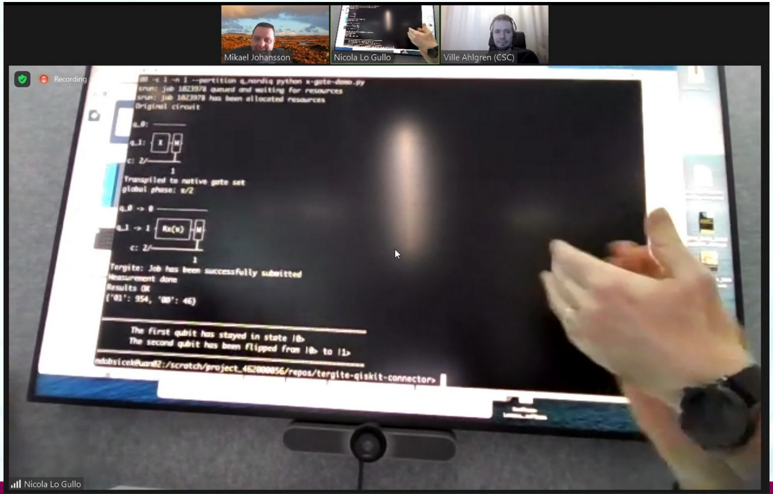




EuroHPC LUMI <-> Chalmers/WACQT QAL 9000

30.3.2022: First quantum job submitted through the LUMI queueing system

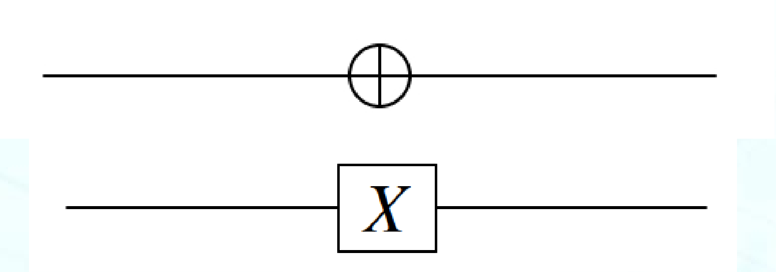
- Connected one LUMI-C node in Finland to the QAL 9000 QC in Sweden, and *successfully ran a cross-border quantum job*



Henrik Nortamo (CSC), Nicola Lo Gullo (VTT/CSC)
Miroslav Dobsicek (Chalmers), Ville Ahlgren (CSC, zoom)

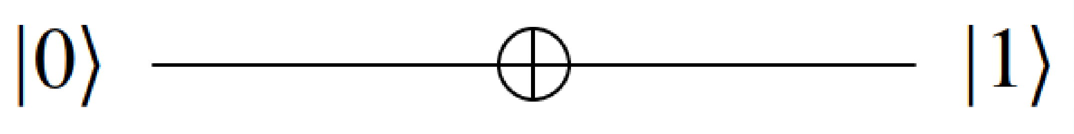
Quantum Circuit Diagrams

- Quantum Algorithms are often shown through circuit diagrams
- One can use either symbols or names; for example the X

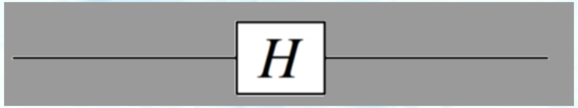


$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

A circuit diagram for NOT on $|0\rangle$ would then look like:



The Hadamard Gate



- Quantum Gate which transforms a qubit from a specific state into a superposition of two states

- $H|0\rangle =$ $$\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}\begin{pmatrix}1\\ 0\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}1+0\\ 1+0\end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix}1\\ 1\end{pmatrix} = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

- Note: The *square* of the amplitude is the probability of the state I.e
  - $\alpha|0\rangle + \beta|1\rangle$; $\boldsymbol{|\alpha|^2+|\beta|^2 = 1}$
  - $\boldsymbol{|\alpha|^2}$ to be in state $|0\rangle$ and $\boldsymbol{|\beta|^2}$ to be in state $|1\rangle$
  - The sum must always be 1

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

Superposition

Qubits can be in a quantum mechanical **superposition** of all values simultaneously

The difference between bits and qubits grows more pronounced with increasing (qu)bit count:

2 bits can describe **4** different states: **00**, **01**, **10**, **11**

2 qubits can describe all **4** states *at the same time*

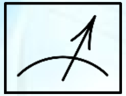
3 bits can describe $2^3 = 2 \times 2 \times 2 =$ **8** different states: **000**, **001**, **010**, **011**, ...

3 qubits can describe all **8** states *at the same time*

20 qubits can describe a ***million*** states, *etc…*

The different states can represent different inputs, on which the computer performs some computation

Measurement

- Even if **several inputs** can be processed at once, **only one answer** will emerge from the computer when you **measure** the result
- $\alpha|0\rangle + \beta|1\rangle$ → **QPU** → $\boldsymbol{\alpha'}|f(0)\rangle + \boldsymbol{\beta'}|f(1)\rangle$ →  → $f(0)$ ***or*** $f(1)$
- The answer depends on the **amplitudes** **α’**, **β’**
- $|\text{amplitude}|^2$ = **probability**; $|\alpha|^2 + |\beta|^2$ **= 100%**

- ***A quantum computer is not deterministic***
- In general, *different answers for the same input*
- This really is a **feature, not a bug!**

Accessing the notebooks

Open a browser on your laptop and navigate to notebooks.csc.fi

Login with the account name given to you – guestNN@neic

The password is ***quantum4all***

Scroll down to *myQLM 1.2.2 notebooks* and click *Launch New* at the bottom.

Click *Open in Browser*. Navigate to Course Material → 2022-NeIC → Notebook-01

Remember to save your edited notebook!