Du classique au quantique : le point de vue des centres de calcul

DE LA RECHERCHE À L'INDUSTRIE

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Outline

- What is a Computing Centre
- Quantum Computing Usage and Integration
- National Hybrid HPC Quantum Initiative

What is a Computing Centre / Data Centre

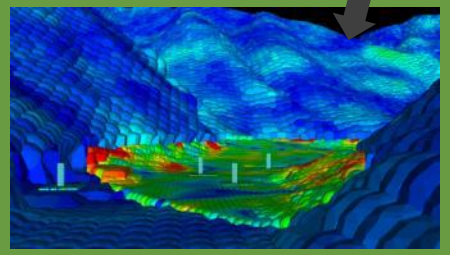
A computing centre is a large installation dedicated to digital processing

- **Processing** resources: computers
- **Storage** resources: disks, magnetic tapes
- **Network** connections: users are all remote
- **Facilities**: power supply and cooling

Cooling/Power

Supercomputer

High Speed Network



Multidisciplinary teams of experts to pilot these exceptional resources and support users

What technologies for high-performance computing?

High-performance computing mostly uses digital technologies from the consumer industry and a few specific components

- The objective is to take advantage of volume markets and limit the specific to what is strictly necessary.

- **Standard processors, memory, and storage**
- **Specific networks related to the need for fast communication between processors**
- **Dense integration linked to the need for energy efficiency and proximity of treatment units**
- **System software developed in community mode**

All performance comes from parallelism

- In processors
- Between processors

Proposed Uses of Quantum Technologies

- **Quantum Technologies can be used**
  - To compute through use of Quantum Processing Unit (QPU)
  - To communicate between QPU
    - To make a Quantum multi-processor or a Quantum cluster
    - Allow for more qubits than a single one can offer
    - A futuristic model but which has allowed scaling of classical computing
  - No quantum storage
    - Only quantum memory is envisaged as a set of specialized qubits, distinct from those of QPUs to reduce the need for computational qubits

How do we imagine to use QPU?

Quantum Computing power is based on Quantum effects

QC cannot be used as classical computers

- It is **not a new port** of application
- It is **a new way of thinking** solutions to problems

Quantum Computer are not general purpose computers

QC solves **specific problems with new algorithms**

Full digital processing needs a solution based on classical + quantum: the **hybrid architecture**

- Main part of application runs on classical computer
- Some phases/algorithm are offloaded on QPU

Hybrid Architecture: Coupling Classical and Quantum

▶ Logical coupling or how to use QPUs in digital processing

- **Weak** coupling
  - A step within a processing chain ("workflow" type)
  - Uses the data center network
  - Requires the ability to share QPU between treatments
  - Only solution if the QPU is very expensive

- **Medium** coupling
  - A local resource to the supercomputer
  - Uses the network of supercomputer
  - Allows you to dedicate a group of QPUs to a classic treatment

- **Strong** coupling
  - Like today's GPU-type accelerators
  - Uses either compute node buses or the supercomputer network
  - Requires high-density, low-cost QPUs

▶ Ideally digital libraries will hide the way link is done

- Will only be available if major applications are demonstrated

Quantum Computing Context

Quantum Computing is a promising technology

- A **new way of thinking**
- Will bring **new algorithms** to solves scientific/mathematical problems

Today Quantum Computers are real but at a small scale and in laboratories

First industrial products will come soon

Competition is strong and many Europeans companies have solutions (HW/SW)

All companies/communities need support from public funding

Quantum computers technology is completely different from classical technology

Everybody need to be prepared

system administrators, operators, developers, end-user

It's time to get ready for computing centres and user communities

Physical integration of quantum computers

What problems quantum computers bring to facilities?

- **QPUs need a specific physical environment**
  - High vacuum
  - Cold temperature close to zero
  - Low vibration (laser)

- **Current computer rooms**
  - Are full of dust
  - Are fresh but the tendency is to increase the operating temperature
  - Vibrate enormously (disks and fans)

- **The solutions planed by start-ups are self contained (integrated facilities)**
  - Pumps, cryostat, marble and laser
  - Start-ups lack experience in making products that can be integrated into a production environment

- **The new data centers have a modular architecture which allows facilities to be adapted to computers**

Strategy

To be ready to use quantum accelerators within a few years

- The use of the quantum computer requires a significant effort from users
- It is mandatory to think quantum
- Classical-quantum coupling remains to be designed

- **Imagine use cases**
- **Experiment algorithms on emulators**
- **Prepare data centers for the use of this type of accelerator**
  - Physical integration
  - Which software environment?
  - Which interface with the data center - type and capacities -?
  - Train teams
- **Support French startups**
  - Pasqal, A&B, C12, Quandela, WeLinQ
  - Help them to move from lab prototypes to insdustrial products

Implementation of the strategy

- **Provide early access to operational environments**
  - Through a Quantum emulator (Atos QLM) since 2018
  - A hardware agnostic software environment
  - Avoid technology locking

- **Installation of QPUs as soon as possible**

- **Plateforme Nationale de Calcul Quantique Hybride from National Quantum Plan**

PNCQH Objectives

Setup a platform to promote

Quantum Computing technologies

Quantum Computing usages

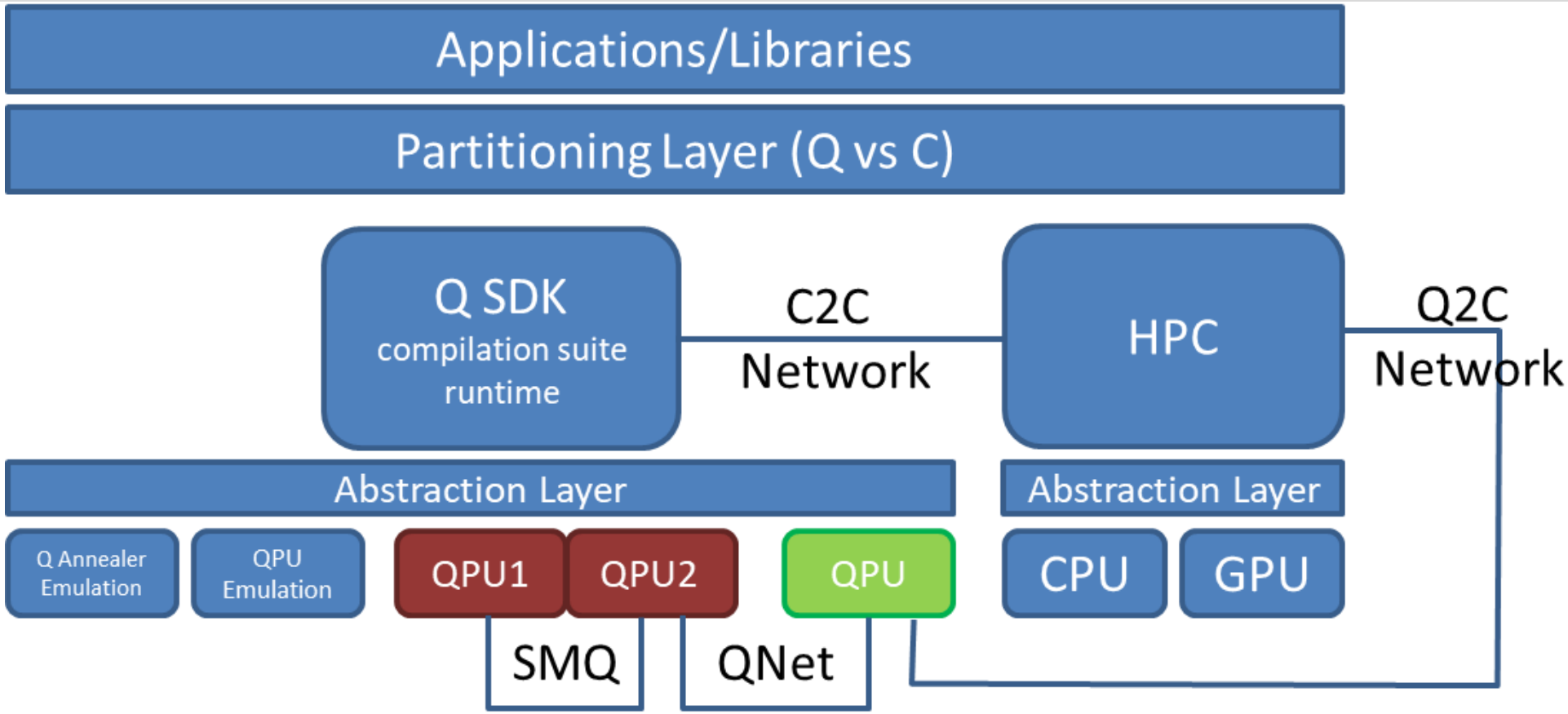
In an HPC environment

- **Hosted in an French computing centre (CEA/TGCC)**
- **Linked to a Supercomputer (GENCI/Joliot Curie)**

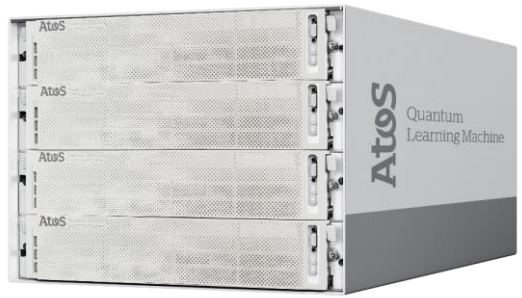
- **Achievement of objectives required**
  - QPU acquisitions
  - Industrial and academic R&D
  - Quantum Computing ecosystem support
  - User communities support

- **Programme will be funded for 72 M€ by PIA4 and will leverage Regional & European funding**

PNCQH Platform Architecture



- **All QPU will use the same SW stack based on Atos QLM + R&D developments**
- **Direct access to QPU will be supported**
- **Designed for NISQ and LSQ**



PNCQH Programme Organization (1/3)

A 5 years programme, with multiple axes

QPU acquisition

4 acquisition phases: standard product or development partnerships

1. Analog QPU
2. Gate based QPU (possibly based on superconducting, photonics or trapped ions)
3. Innovative QPU technologies (such as carbon nanotubes, cats qubits, self-stabilized architectures, …)
4. QPU upgrades and acquisition of emergent promising technologies

Alice & Bob

C12

QUANDELA

PASQAL

IQM

PNCQH Programme Organization (2/3)

R&D programme with industrials and academics

Results will be implemented on the platform

Mains thematic are:

- **Deployment**
  - QPU integration and hybrid architecture (QLM, Cloud, HPC, …)
  - Software environment (development tools, runtime)
- **Applications**
  - Optimization and machine learning
  - Simulation of physical systems
- **Exploration**
  - Noise characterization and mitigation
  - Quantum links for secure/safe/reliable global computation

PNCQH Programme Organization (3/3)

QC ecosystem and User community support

- PNCQH technologies access through a **cloud-based solution**
  - Cloud Provider will provide access to similar QC resources found in the hybrid HPC/QC platform to academics (R&D, training, etc.)

- Hybrid QC dissemination
  - Establish a network of **French quantum competence centres**
    - label "Maison du Quantique »
  - Dissemination, training, acculturation (e.g. **workshops**, **hackathons**, etc.)
  - Scientific and industrial use cases development: National Quantum PAck and European Quantum Packs (ex. through a quantum CoE transversal to existing HPC CoEs)

Conclusion

- **Quantum computing is close to be reality in computing centres**
- **Many topics are still work in progress and many challenges are still open**
- **But all actors preparation is initiated**
  - Computing centres
  - Developers
  - End-users

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Merci de votre attention