Forum TERATEC 24

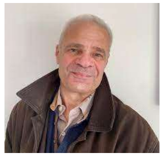
Unlock the future

# Software environments for quantum computing

***Workshop organised and moderated by***


*Patrick Carribault, Fellow, CEA*

*Olivier Hess, Quantum Computing Lead France, Eviden*



*Jean-Philippe Nominé, HPC Fellow, HPC Strategic Collaborations Manager, CEA*



May 29 & 30, 2024 - PARC FLORAL PARIS

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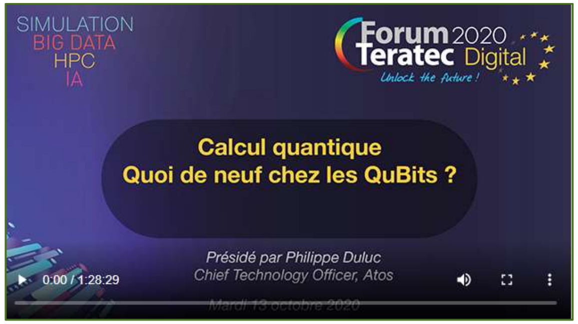




**In 2024 we continue our series of quantum computing workshops at TERATEC Forums, organised by CEA and EVIDEN since many years**

- **2023 Quantum, the future of HPC?** https://teratec.eu/gb/forum_2023/atelier_1.html
- **2022 What's new with qubits? A European view** https://teratec.eu/gb/forum_2022/atelier_5.html
- **2021 Europe is on its way towards “Hybrid Qomputing“** https://teratec.eu/gb/forum_2021/atelier_1.html
- **2020 Quantum computing: what's new in QuBits?** https://teratec.eu/gb/forum_2020/atelier_3.html
- **2019 Quantum computing : which applications will benefit ?** https://teratec.eu/gb/forum_2019/atelier_2.html
- **2018 Quantum revolution is here** https://teratec.eu/gb/forum_2018/atelier_3.html
- **2016 Specialised computing architectures : helpers or challengers ?** https://teratec.eu/gb/forum_2016/atelier_4.html

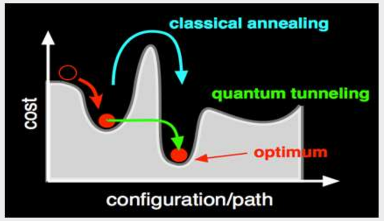
# A complex eco-system

- **Various qubits technologies**

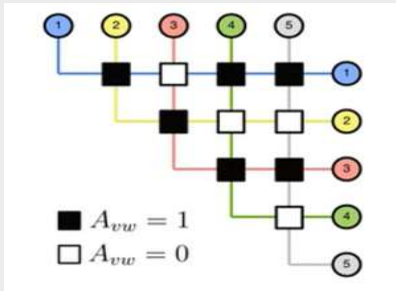
| Super-conducting | Trapped ions | Photons | Silicon qubits | Cold Atoms and Misc |
|---|---|---|---|---|

- **Three main « Programming models »**

### Quantum Annealers

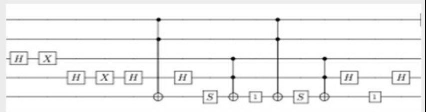



### Quantum Simulators



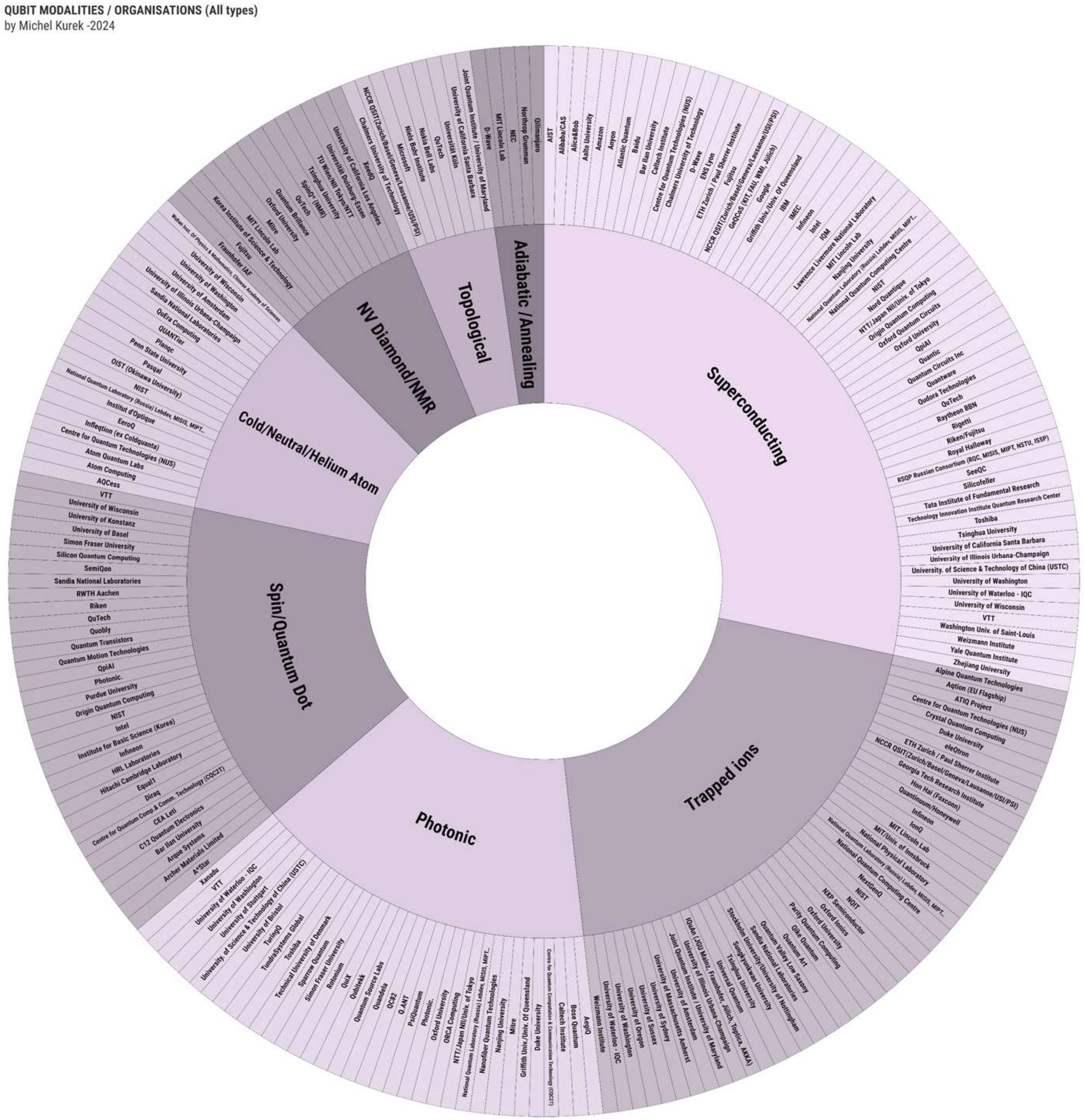

### Quantum Gate based Computers

**Quantum Programs**



# The full picture
# ☺ !

**Credits to Michel Kurek - MultiVerse**

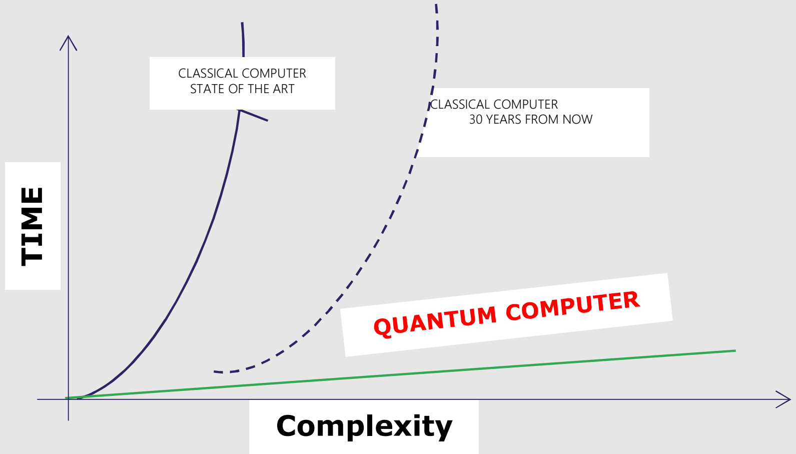



Technology & providers
(Private & Academic)

# NEW POTENTIAL & COMPUTING PARADIGM

## HPC/QC in Theory

- An unprecedented exponential computing power
- Up to $2^N$ faster than a classical computer
- Exascale beaten with only 60 (perfect) qubits!




## But

- No obvious « application portability » from Classical to Quantum Computing
  - ➔ New algorithms have to be designed
  - ➔ Existing algorithms have to be adapted (if possible)
- Not all QC speed-ups are exponential, and classical HPC keeps making progress on different « complex » problems
- Classical HPC and Quantum will co-exist
  - ➔ Need to deal w/ Hybrid Mode (w/ various quantum technologies + emulation)
  - ➔ Need to work on hybrid software stack

## Workshop Approach

- Low-level software stack
- Tools, platform & middleware
- Algorithm and high–level software stack


# The use cases most likely to have the highest value over the long term are in the finance and life sciences sectors.

Incremental impact | Significant impact | Disruptive impact

| Problem archetype | Finance | Life sciences | Aerospace and defense | Chemicals | TTL[1] | Automotive and assembly | EPNG[2] |
|---|---|---|---|---|---|---|---|
| **Factorization** eg, breaking RSA encryption | Disruptive impact | Incremental impact | Disruptive impact | Incremental impact | Significant impact | Incremental impact | Incremental impact |
| **Quantum simulation** eg, calculating a molecule's spectrum | Incremental impact | Disruptive impact | Significant impact | Disruptive impact | Significant impact | Significant impact | Significant impact |
| **Optimization** eg, finding the best schedule for planes | Disruptive impact | Disruptive impact | Significant impact | Incremental impact | Disruptive impact | Significant impact | Significant impact |
| **Quantum ML and AI** eg, processing natural language | Disruptive impact | Significant impact | Incremental impact | Significant impact | Significant impact | Significant impact | Significant impact |
| **Sampling and search** eg, finding a match in an unstructured database | Disruptive impact | Incremental impact | Incremental impact | Incremental impact | Significant impact | Significant impact | Incremental impact |

[1] Travel, transport, and logistics.
[2] Electric power and natural gas.

Source: Expert interviews

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- **Part I: 15:00-16:30**
  **General programming environments and tools**

  - EVIDEN
  - NVIDIA
  - CEA

**Cyril Allouche**
Eviden
VP R&D Quantum

**Esperanza Cuenca Gómez**
Nvidia
Developer Relations Manager for Quantum Computing

**Sébastien Bardin**
CEA-List
Senior researcher CEA List

**Christophe Chareton**
CEA
Researcher CEA List

- **Part II: 17:00-18:30**
  **The very necessary contributions of Qubits providers**
  **From physical simulation to emulation of qubits and software stack elements**

  - Quandela
  - Pasqal
  - Alice&Bob

**Jean Senellart**
Quandela
Chief Product Officer

**Daniel García Guijo**
PASQAL
Technical Project Delivery Manager

**Laurent Prost**
Alice & Bob
Product Manager

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Cyril Allouche

Eviden

VP R&D Quantum

## Large Scale Quantum Simulation with Qaptiva

- HPC is an essential relay, if not the relay, for quantum computing, in order to accelerate the development of use cases as well as the convergence with classical computing infrastructures. First of all, because the current state of quantum technologies does not allow the experimentation of computational programs of relevant size. Only the numerical simulation of quantum computing makes it possible to address problems beyond a dozen qubits. Secondly, because the characteristics of quantum computing make it an accelerator, called upon to effectively support classical architectures, and not to replace them. In this talk, we will show how the Qaptiva solutions address this double convergence of HPC for quantum and quantum for HPC.

- *Cyril Allouche is the Director of Research and Development (R&D) in Quantum Computing at Eviden. Cyril Allouche is a qualified engineer, holding a degree from Ecole Polytechnique in Paris, as well as a PhD in Computer Science from University of Paris Sud. Cyril has been responsible for Research and Innovation at Eviden, an Atos company since 2013, and has been leading Atos' Quantum R&D program since its inception in late 2015. Cyril plays a pivotal role in advancing the field of quantum computing and his vision extends to infrastructure convergence, constructing frameworks that integrate quantum computing with high-performance computing (HPC) or cloud solutions. As Eviden continues to thrive in the HPC and quantum computing domains, Cyril Allouche remains at the forefront of innovation, driving the convergence of cutting-edge technologies and shaping the future of computational possibilities. He is also an inventor of 13 patents.*

## Towards the Quantum-Accelerated Supercomputer

- Valuable quantum computing will integrate tightly with and depend on classical high-performance computing and AI. Such a hybrid system needs a programming model that enables easy and performant coprogramming across quantum and classical resources. NVIDIA CUDA Quantum is an open-source platform for integrating and programming quantum processing units (QPUs), GPUs, and CPUs in a single system. Additionally, the ability of scientists, developers, and researchers to simulate quantum circuits on classical computers is vital for quantum computing. NVIDIA cuQuantum is an SDK of optimized libraries and tools for accelerating quantum circuit simulations. During this talk CUDA Quantum and cuQuantum main features will be presented, as well as some representative benchmarks and examples.
- *Esperanza Cuenca Gómez is Developer Relations Manager for Quantum Computing at NVIDIA. She has a background in quantum computing, consumer finance, banking, and strategy consulting. As an industrial engineer, Esperanza sees applied science and engineering as ways to build new technologies, solve problems, and contribute to society.*

**Esperanza Cuenca Gómez**
Nvidia
Developer Relations Manager for Quantum Computing

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CEA
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## Quantum programming and automatic code analysis

- For the nascent quantum software engineering community, a fundamental challenge lies in the design and development of programming support tools. The problem of code validation is particularly acute, in a context where strategies derived from classical programming (tests and assertion verification) do not appear to be suitable. The behavior of quantum processes - indeterminism, destructive measurements - makes them intrinsically inoperative. We therefore need to design high-performance code verification and validation strategies that are robust under the particular constraints of the physical laws invoked. In this respect, methods derived from static and formal code analysis are the most promising alternative. To meet the challenge of quantum code validation, we need to adapt the know-how and formal analysis methods we have developed in the classical context to the quantum context. This presentation introduces the different aspects of the induced work program (formalization of quantum programs, hybrid measurement and control processing, certification of compilation chains, etc.) as well as the solution, Qbricks, that we are developing in our laboratory.
- *A researcher at CEA/List since 2018, Christophe Chareton is interested in techniques for validating quantum programs, particularly those implementing formal methods and static analysis. In recent years he has developed the Qbricks tool, a pioneer in the field of functional verification in quantum computing.*
- *Sébastien Bardin is a Senior Researcher at CEA List, specializing in formal methods and program analysis. He recently developed the software side of CEA's quantum program, and launched the "quantum program analysis" and QBricks research axes. Sébastien is a Fellow at CEA.*

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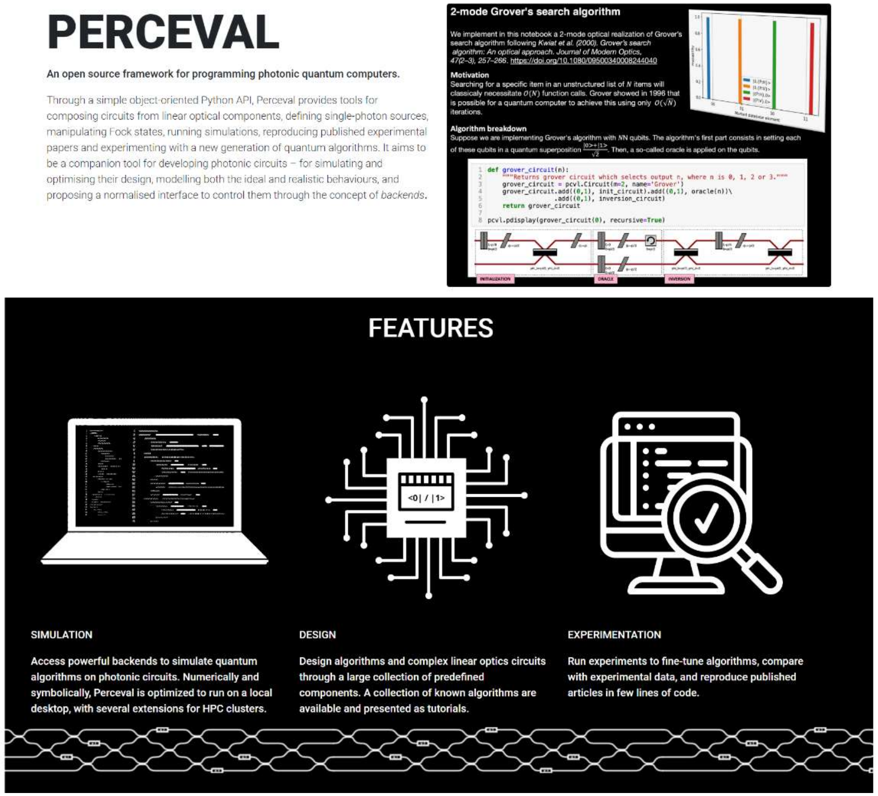
## Perceval: An open source framework for programming photonic quantum computers




Jean Senellart

Quandela

Chief Product Officer

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## From neutral atom arrays to real world applications

- Building a quantum computer is a herculean task but using it to solve real world problems doesn't need to be. At PASQAL, we're creating a software stack that allows end users to go from targeting individual atoms and simulating quantum systems, to using our QPU to solve aerodynamics problems with no quantum knowledge at all.
- *Daniel Guijo is a Technical Project Delivery Manager at Pasqal. He's a physicist from the University of Oviedo, with experience in quantum software development and technical management. Furthermore, he is deeply involved in the open-source ecosystem as a Quantum Fellow in Quantum Quipu and a Mentor in the Quantum Open Source Foundation, developing educational and research projects with students and young professionals, and focusing on the applications of quantum computing to the sustainability domain.*

Daniel García Guijo
PASQAL
Technical Project Delivery Manager

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## From physical qubits to logical qubits with cat qubits

- Quantum error correction is necessary to achieve the promise of quantum computing, and implementing it requires the development of a new abstraction: the logic qubit. How are logical qubits created? How and for what applications will they be used? How can we get prepared for their arrival?
- *Laurent Prost has a background in applied mathematics and over 13 years' experience in Product Management. He is leading Alice & Bob's efforts to make cat qubits accessible to as many people as possible, with cloud access to a quantum computer, emulation tools, tutorials, and more.*

Laurent Prost
Alice & Bob
Product Manager