COLIBRITD

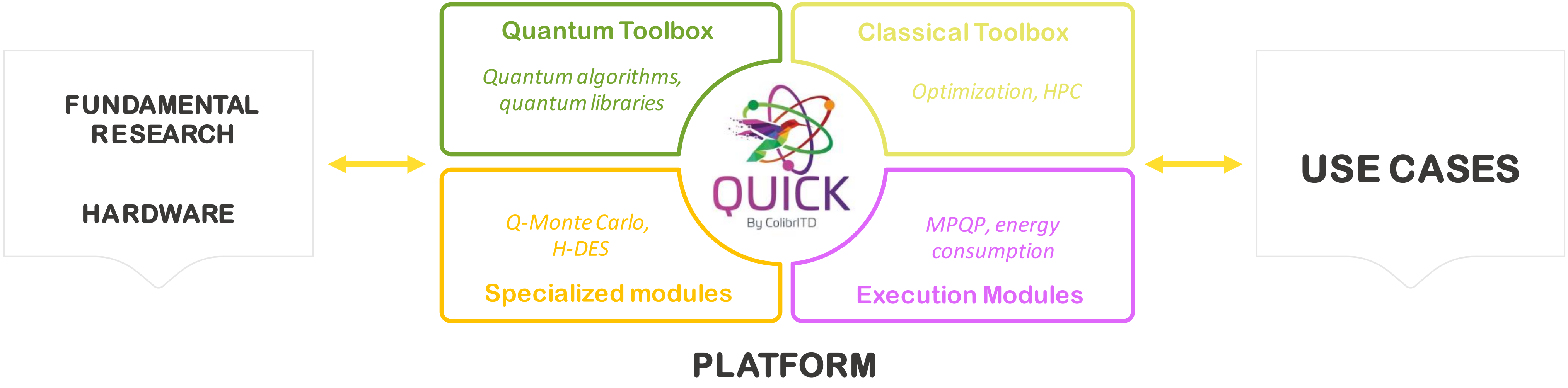
Forum TERATEC 23

Unlock the future

31 MAI & 1er JUIN 2023 • Au Parc Floral, Paris

Un événement organisé par infoprodigital Teratec

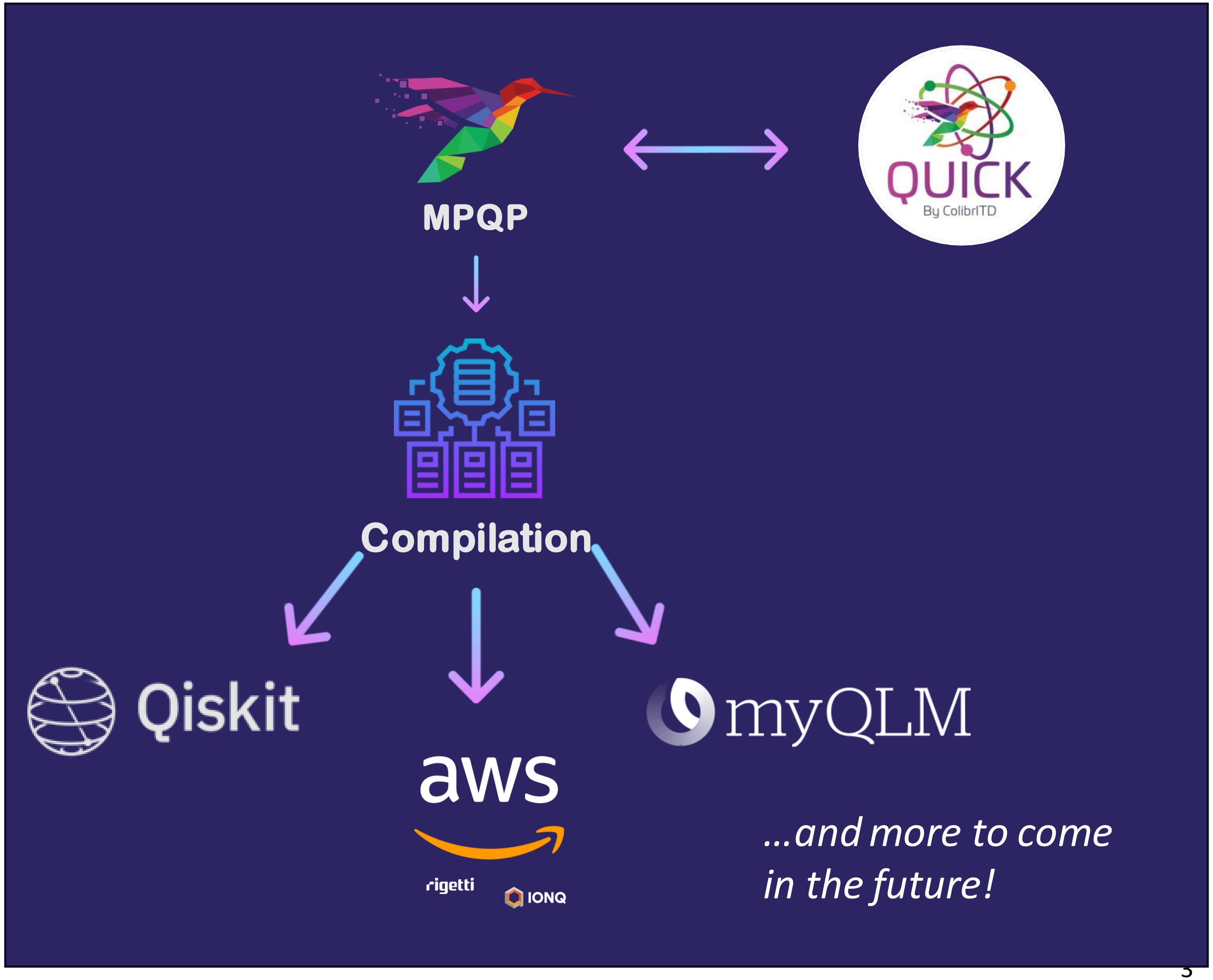
QaaS: Quantum as a Service



MPQP: Multi Platform Quantum Programming

A UNIFIED AND INTUITIVE PROGRAMMING LIBRARY

1. One language, all platforms
2. Helpful for designing hybrid Q/C algorithms
3. Wrap user code from a specific language to another through our library



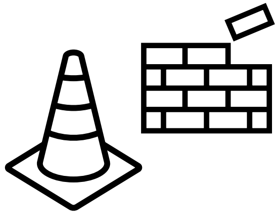
VQA: Variational Quantum Algorithms

A *quantum equivalent* of neural networks → **HYBRID**

NISQ compatible ←

- Noise resilient
- Low cost in the number of qubits

An important optimization step → An algorithm to compute circuit distances



WORK IN PROGRESS

Architecture is key! → A library to rapidly test various architectures (called Ansätze)

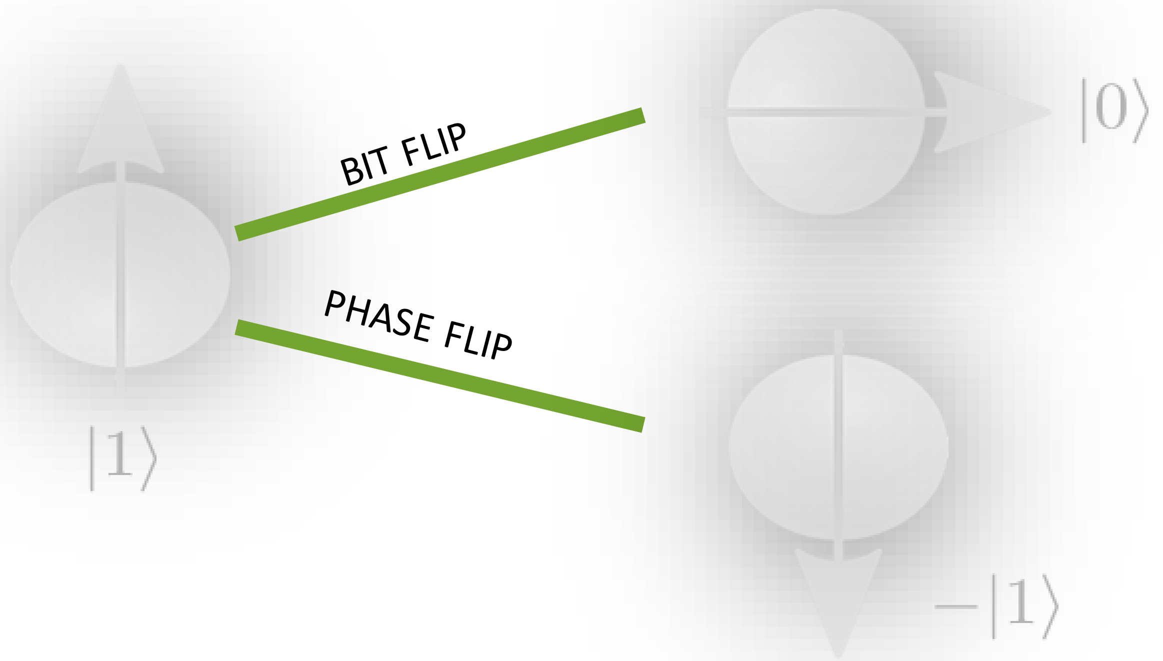
Noise study

Quantum Noise

Bit Flip and Phase Flip

Gate noise

The main obstacle to reach quantum advantage



Noise study

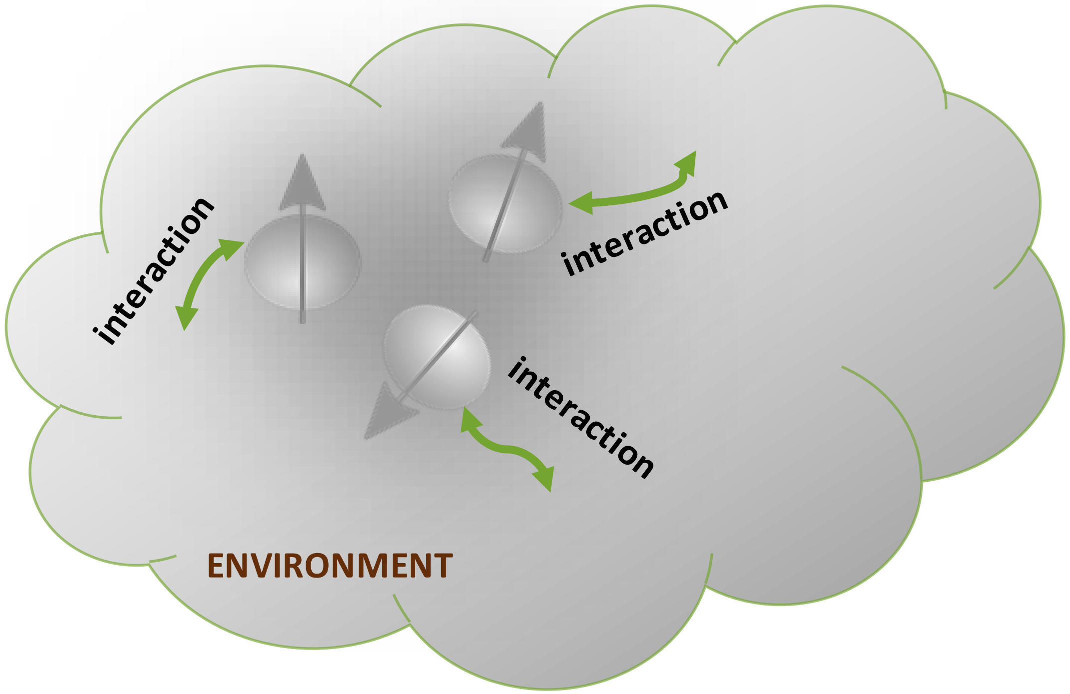
Quantum Noise

Bit Flip and Phase Flip

Thermal noise

Interaction with the environment

The main obstacle to reach quantum advantage



Noise study

Quantum Noise

The main <u>obstacle</u> to reach quantum advantage

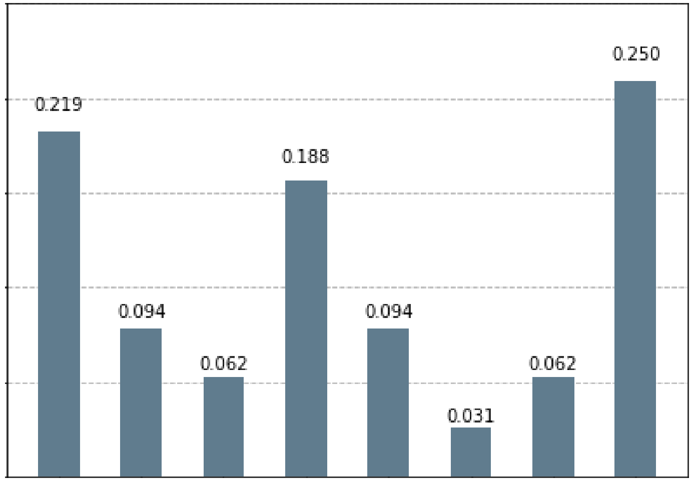
Bit Flip and Phase Flip

Thermal noise

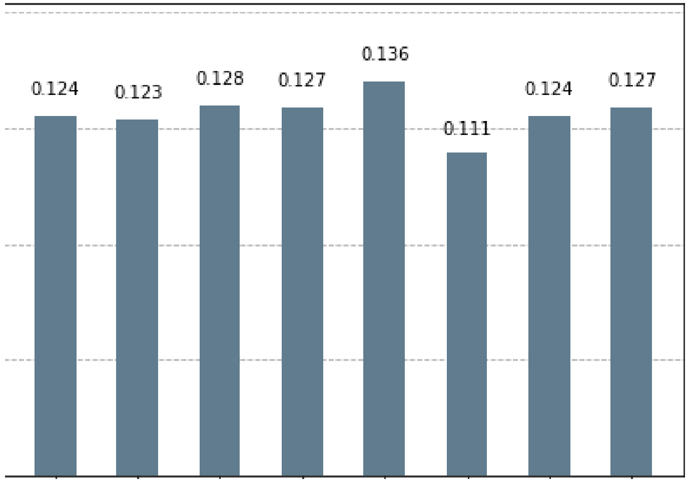
Shot noise

Statistical

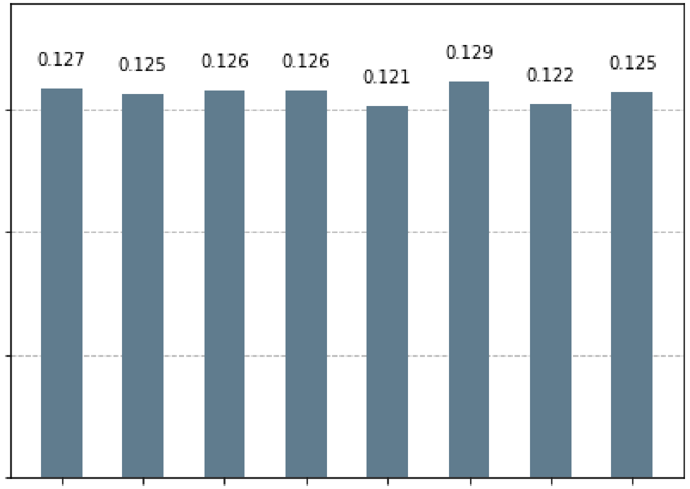
32 shots



1024 shots



32768 shots



Noise study

Quantum Noise

The main <u>obstacle</u> to reach quantum advantage

- Bit Flip and Phase Flip
- Thermal noise
- Shot noise

<u>Close to **hardware providers**</u>

Noise study – Different directions

Dynamical Ansätze	Classical Shadows	Classical optimizers	Observable approach
Adapting the structure of the quantum circuit through the computation	Estimating quantum properties of the state thanks to classical post processing	Implementing constrained, unconstrained and noisy state of the art optimizers (SPSA, Bayesian…)	Evaluating expectation values of observables modeling the problem to solve

Quantum Monte-Carlo

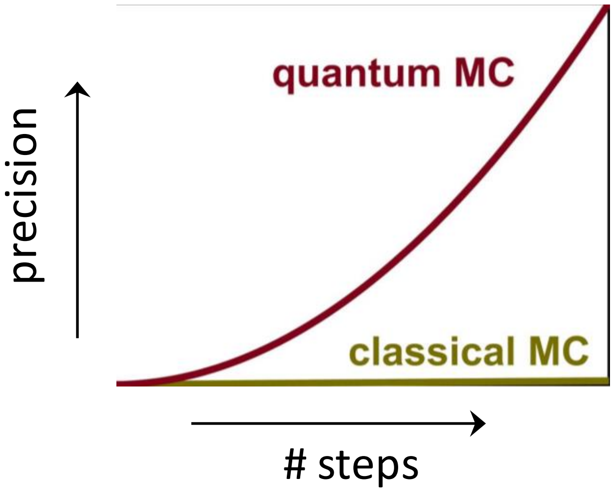
What

- **<u>Monte-Carlo simulations</u>:** to predict possible outcomes of an uncertain event through repeated random sampling

- **<u>Quantum algorithm</u>**: quantum state that models the system given by the translation from classical to quantum

Advantage

Quantum algorithm provides a **<u>quadratic speedup</u>** over classical Monte Carlo methods



Application

- **<u>Turbulent mixing</u>**: complex fluid dynamics (*storm simulations, ocean modeling…)*

- **<u>Combustion</u>**: chemically reacting turbulent flows (*practical combustion systems efficient and environmentally friendly*)

H-DES: Hybrid Differential Equation Solver

Pillar of mathematical modeling

From atmospheric phenomena to atomic interactions, **they are everywhere**

! Real processes are **nonlinear** !
Numerical errors harder to control

In classical methods the domain is discretized
Finer grids = higher precision + computational time

QUANTUM COMPUTING CAN IMPROVE THIS APPROACH AND UNLOCK OTHERS

Exponentially finer grids and error-free continuous methods

Potentially reducing energy consumption*

*Researchers estimate quantum computers consume thousands of times less energy than HPC [1, 2, 3]

H-DES: Hybrid Differential Equation Solver

There are **NISQ-ready** hybrid algorithm

Complexity of quantum states

Classical optimization

NISQ-incompatible subroutines can be replaced by VQCs

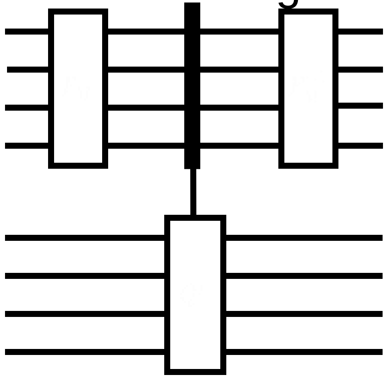
Quantum Finite difference methods*

Variational quantum state's amplitudes

Continuous methods

Expectation value of a variational quantum state

Quantum **A**mplitude **E**stimation **A**lgorithm



Flexibility! Adaptable to any system described by PDEs!

ONLY a small part of the algorithm is delegated to a Quantum Computer **

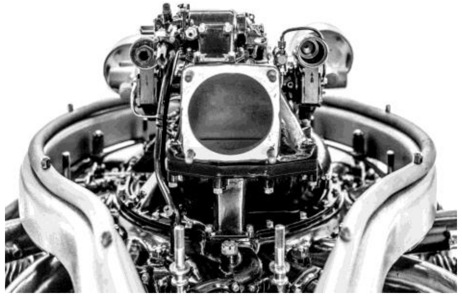
* **M. Lubasch *et al.*, Phys. Rev. A**. 2020, 101, 010301(R).

****F. Gaitan,** Adv. Quantum Technol. 2021, 4, 2100055

Use cases

NOW:

Material Deformation & Combustion



WHY?

Better simulations streamline prototyping and can reduce carbon emissions

- Both processes are nonlinear: ideal to test quantum advantage
- Both demand power-hungry HPC: Quantum computing might alleviate it

Partners, collaborations

UNIVERSITÉ TOULOUSE III PAUL SABATIER
Université de Toulouse

SKALNATÉ PLESO

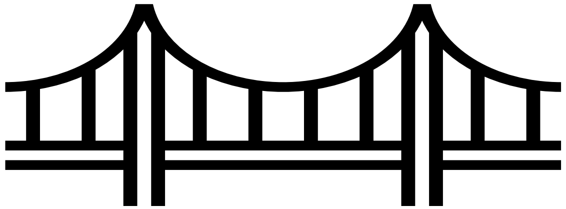
icb
Laboratoire Interdisciplinaire Carnot de Bourgogne

INSTITUT DE RECHERCHE
femto-st
SCIENCES & TECHNOLOGIES

UNIVERSITY OF MARYLAND 1856

UBFC
UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ

ENSTA ParisTech
université PARIS-SACLAY



ONERA
THE FRENCH AEROSPACE LAB

GENCI

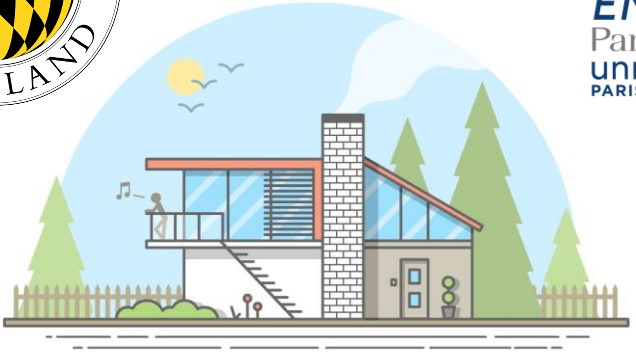
IBM Q™

EVIDEN

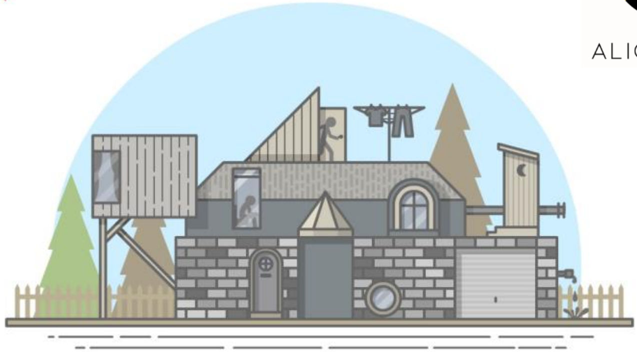
aws
Amazon Braket

Wolfram Mathematica

ALICE & BOB



Academic



Industry

Further research

Quantum Advantage

BOTH IN TIME AND ENERGY

Comparing the quantum computers of today and tomorrow with their classical supercomputer counterpart.

Quantum Games

Quantum Contextuality

A QUANTUM PROPERTY TO INVESTIGATE

For possible applications and connections with other important quantum features.

Publications

Quantum supremacy? Not so fast.

What stands in the way of variational quantum algorithms toward the quantum advantage

Getting to know Quantum Fourier Transform

Quantum Entanglement: how to classify it?

MEDIUM

(I Can't Get No) SATisfaction

Quantum Machine Learning: A quick overview

STAR WARS: IBM, AMAZON, and ATOS for Hybrid Quantum Algorithms: Fighting for Solving Differential Equations

To reject or not to reject, that is the question.

Ways for Quantum Computing to help fight climate change

How to bring Quantum Programming to everyone?

Not all cats are grey at night — comparing different qubit technologies

Interpretations of quantum mechanic - The diatribe between realists and orthodox before Bell's theorem

ARTICLES

[1] G. Amouzou, J. Boffelli, **H. Jaffali**, K. Atchonouglo, and F. Holweck. "Entanglement and Nonlocality of Four-Qubit Connected Hypergraph States." *International Journal of Quantum Information* 20, no. 03 (April 2022): 2250001. .

[2] F. C. V. de Brito, I. G. da Paz, **J. B. Araujo**, and M. Sampaio. "Biphoton Phase-Space Correlations from Gouy-Phase Measurements Using Double Slits." *Physical Review A* 104, no. 6 (December 17, 2021): 062430.

[3] F. Holweck, **H. de Boutray**, and M. Saniga. "Three-Qubit-Embedded Split Cayley Hexagon Is Contextuality Sensitive." *Scientific Reports* 12, no. 1 (May 26, 2022): 8915.

[4] **H. de Boutray**, F. Holweck, A. Giorgetti, P.-A. Masson, and M. Saniga. "Contextuality Degree of Quadrics in Multi-Qubit Symplectic Polar Spaces." arXiv, April 9, 2022

[5] **Milazzo, N.**, Giraud, O., Gramegna, G., & Braun, D. "Principles of quantum functional testing." arXiv, September 23, 2022.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