Chapitre 2: Calcul quantique à l’ère NISQ

Les ordinateurs quantiques sont bruités

- Les qubits sont très sensibles à leur environnement
- La profondeur des circuits (nombre de couches de circuits) allonge la durée d'exécution et, par conséquent, ajoute et propage des erreurs.
- Les circuits doivent être aussi courts que possible
- Le circuit doit être exécutable sur une machine donnée

https://www.vecteezy.com/vector-art/23929483-noise-pollution-harmful-sounds-causing-disturbances-affecting-health-and-environment

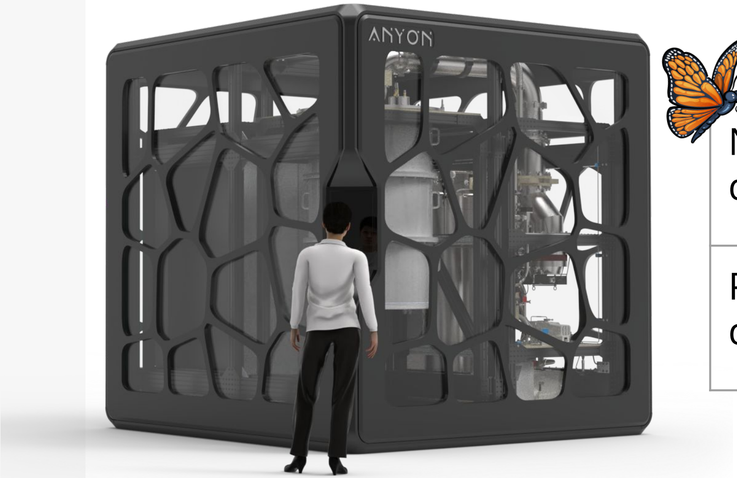
NISQ

Noisy
Intermediate
Scale
Quantum
Computers

Processeurs quantiques disponibles aujourd’hui

Haut niveau de bruit

➔ Nombre limité de qubits
➔ Nombre d’opérations unitaires (portes) limité

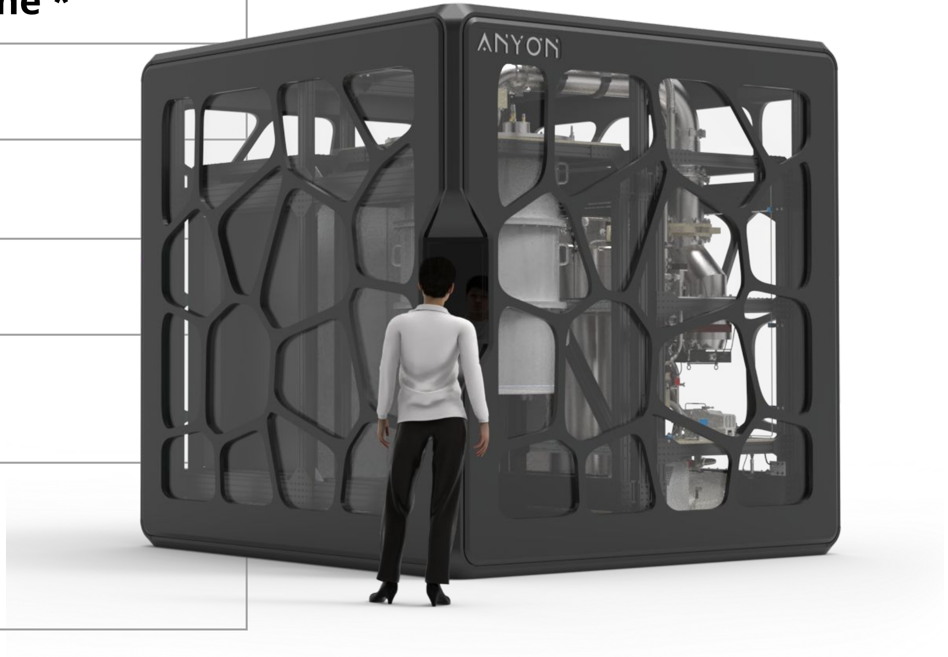


MonarQ

Nombre de qubits	24 qubits
Profondeur de circuit	~350 portes à un qubit

MonarQ métriques de performance

Métrique	Valeur médiane *
T_1	9.4 µs
$T_{2,Ramsey}$	1.3 µs
$T_{2,Echo}$	3.3 µs
Fidélité des portes à un qubit	99.75%
Fidélité de la porte CZ	96.2%



*Basé sur les données du 4 au 18 décembre 2024

Vers l’ère FTQC

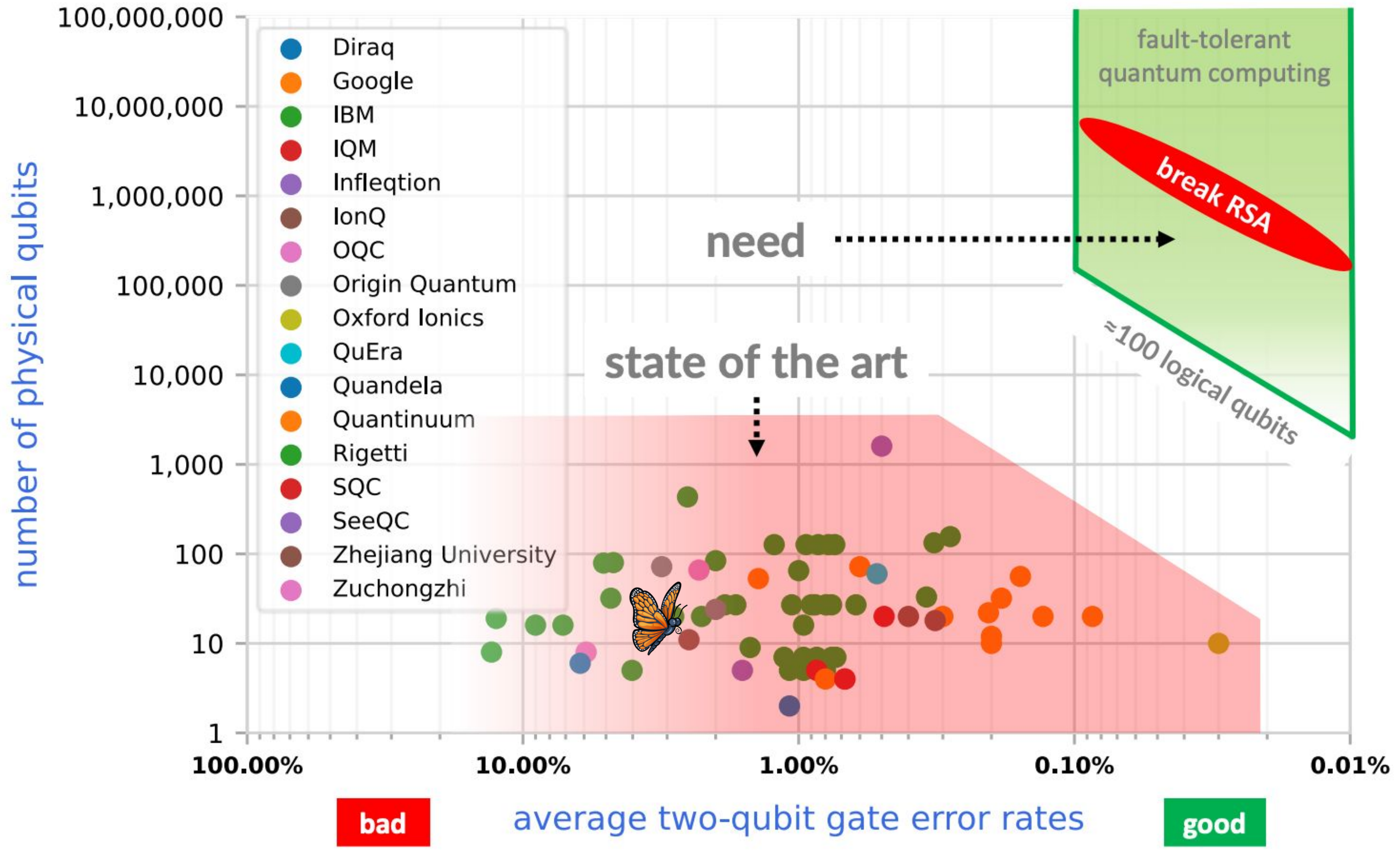
Fault **T**olerant **Q**uantum **C**omputers

Objectif à long terme de l'informatique quantique

Ordinateurs quantiques avec correction d’erreurs

- ➔ Plus grand nombre de qubits nécessaires pour faire des qubits **logiques** (1000:1)
- ➔ Qubit logique: robuste aux erreurs
- ➔ Sinon on parle de **qubits physiques**
- ➔ Augmentation de la profondeur des circuits

Source : Eur. Phys. J. A (2023) 59:94 https://doi.org/10.1140/epja/s10050-023-01006-7



Quand utiliser un ordinateur quantique?

Un PC suffit

Problèmes compatibles avec NISQ

FTQC requis

- Arithmétique
- Regarder ses courriels

- Chimie
- Apprentissage machine
- Optimisation

... et d’autres domaines de recherche

- Algorithme de Shor
- Transformé de Fourier quantique
- Algorithme de Grover

Adapté de https://learning.quantum.ibm.com/course/quantum-computing-in-practice/what-problems-are-quantum-computers-good-for

NISQ Étude de cas

Chimie

Greene-Diniz et al. *EPJ Quantum Technology* (2022) 9:37
https://doi.org/10.1140/epjqt/s40507-022-00155-w
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Modelling carbon capture on metal-organic frameworks with quantum computing

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Abstract

Despite the recent progress in quantum computational algorithms for chemistry, there is a dearth of quantum computational simulations focused on material science applications, especially for the energy sector, where next generation sorbing materials are urgently needed to battle climate change. To drive their development, quantum computing is applied to the problem of CO_2 adsorption in Al-fumarate Metal-Organic Frameworks. Fragmentation strategies based on Density Matrix Embedding Theory are applied, using a variational quantum algorithm as a fragment solver, along with active space selection to minimise qubit number. By investigating different fragmentation strategies and solvers, we propose a methodology to apply quantum computing to Al-fumarate interacting with a CO_2 molecule, demonstrating the feasibility of treating a complex porous system as a concrete application of quantum computing. We also present emulated hardware calculations and report the impact of device noise on calculations of chemical dissociation, and how the choice of error mitigation scheme can impact this type of calculation in different ways. Our work paves the way for the use of quantum computing techniques in the quest of sorbents optimisation for more efficient carbon capture and conversion applications.

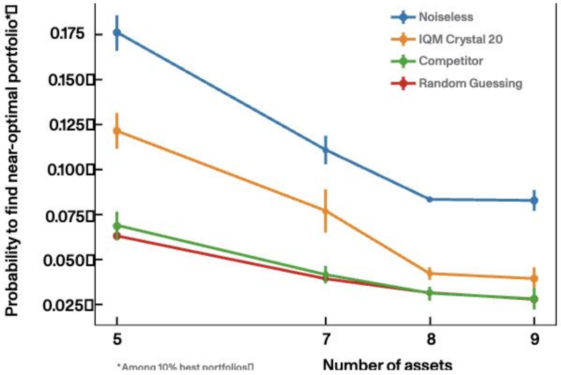
Keywords: Quantum computing; NISQ; Carbon capture; Climate change; Quantum algorithms

Source : https://epjquantumtechnology.springeropen.com/articles/10.1140/epjqt/s40507-022-00155-w

Optimisation

IQM and DATEV advance quantum solutions for portfolio optimization

In our collaboration with DATEV, we developed a specific quantum algorithm tailored to the company's product portfolio optimization challenge. By using the data of DATEV and applying advanced transpilation techniques, we were able to execute the algorithm on our quantum hardware, leveraging a quantum processing unit (QPU) with 20 qubits.



Source : https://www.meetiqm.com/lp/the-future-of-portfolio-optimization-is-in-quantum

NISQ Étude de cas

Apprentissage machine (QML)

Applying Quantum Autoencoders for Time Series Anomaly Detection

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Abstract

Anomaly detection is an important problem with applications in various domains such as fraud detection, pattern recognition or medical diagnosis. Several algorithms have been introduced using classical computing approaches. However, using quantum computing for solving anomaly detection problems in time series data is a widely unexplored research field.
This paper explores the application of quantum autoencoders to time series anomaly detection.

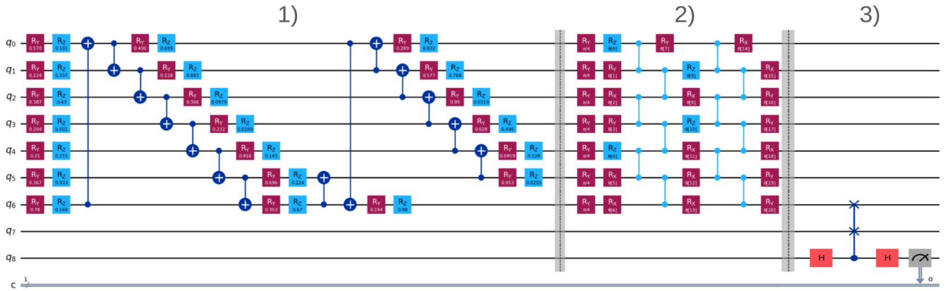

Fig. 8: Illustration of a circuit optimized for execution on real quantum hardware before transpilation.

Source : https://arxiv.org/abs/2410.04154

et d’autres domaines actifs de recherche

Science des matériaux

Quantum Algorithm for Vibronic Dynamics: Case Study on Singlet Fission Solar Cell Design

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[6] *Acceleration Consortium, Toronto, ON, M*

Vibronic interactions between nuclear motion and electronic
modeling of photochemistry. However, accurate simulations of f
ics are often prohibitively expensive for classical methods beyo
present a quantum algorithm based on product formulas for sim
eral vibronic Hamiltonian in real space, capable of handling an a
and vibrational modes. We develop the first trotterization schen

Biologie

A biological sequence comparison algorithm using quantum computers

Büsra Kösoglu-Kind[1], Robert Loredo[2,3], Michele Grossi[4], Christian Bernecker[5],
Jody M. Burks[2] & Rüdiger Buchkremer[1]

Genetic information is encoded as linear sequences of nucleotides, represented by letters ranging from thousands to billions. Differences between sequences are identified through comparative approaches like sequence analysis, where variations can occur at the individual nucleotide level or collectively due to various phenomena such as recombination or deletion. Detecting these sequence differences is vital for understanding biology and medicine, but the complexity and size of genomic