The BACQ Project on Quantum Computing Benchmarks

BACQ: « Benchmarks applicatifs pour les calculateurs quantiques »

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Quantum Computing Engineer
HPC user Forum – October 08th, 2025

Content overview

01 The BACQ Project

BACQ: Application-oriented benchmarks for quantum computers

BACQ
MetriQs-France

- **Main goal**
  - A **measuring instrument** for the **objective evaluation** of the **quantum computing practical performance**
  - Unbiased, "universal", long-lasting, reproducible, **widely-used and recognized** to serve as **common reference**

Benchmarks adapted to analog to gate-based machines NISQ to FTQC

- **Purpose**
  - Comparing different quantum computing technologies with classical computers
  - Assessing the progress towards useful quantum computing
- **How?**
  - An open-access set of benchmarks close to real applications, meaningful for industrial end-users

BACQ: A collaborative R&D project

Key figures

- 3-year project (Sept. 2023 – August 2026)
- 6 partners : Thales, Eviden, CEA, CNRS, Teratec, LNE
- 7,2 FTE/year
- 3,9 M€ budget

Access to QC and emulators

- Direct collaboration with QPU providers
- HQI / CEA TGCC (HPC-QC)
- EuroHPC (EU QC hosting sites)
- Eviden Qaptiva Appliance

Major outcomes after 3 years

- First set of validated application-oriented benchmarks
- Multi-criteria notation model for quantum computers

Long term vision

- LNE, as independent trusted third party:
- Makes the benchmarking tools publicly available
- Collects and publishes the evaluation results

Maximizing impact

- Consultations (Industry – Tech. providers and End-users - , Academia, Gov. agencies…)
- EU and international cooperation (R&D teams, benchmarking initiatives…)
- Standardization (AFNOR, CEN-CENELEC, ISO/IEC, IEEE)
- Publications & Communications

BACQ: Application-oriented benchmarks for quantum computing

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❖ Scientific approach

*Benchmarks adapted to
analog to gate-based machines
NISQ to FTQC*

1. **Definition of reference problems to be solved**
   - [Optimization – Simulation of quantum physics – Linear system solving – Factorization]
2. **Definition of technical metrics for their resolution**
   - [Computational and energetic]
3. **Aggregation of the metrics and multi-criteria analysis to derive high-level operational indicators**

BACQ: The generic reference problems considered

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Simulation of Quantum Physics (Ising model in transverse field, 2D Hubbard model, BCS model)

Optimization (including MAXCUT / Q-Score)

Linear Systems Solving

Prime factorization

BACQ: The technical metrics

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- **[Simulation of Quantum Physics]**
  - Many-body Score
  - Many body fidelity
- **[Optimization]**
  - Q-score MaxCut
  - Accuracy indexed by noise level
  - Compilation-dependent criteria
  - Probability of obtaining the optimum
  - Min case/Max case gap with regards to the optimum
  - Size of the problem in number of variables, number of qubits to solve the problem, class of problem addressed
- **[Linear Systems Solving]**
  - Accuracy indexed by noise level
  - Compilation-dependent criteria
  - Probability of solving the problem, number of variables and precision in qubits
  - Algorithm-dependent energetic criteria
- **[Factorization]**
  - Probability to factorize
  - Size in bits of the calculated number
- **[Generic]**
  - Computation time
  - Latency
  - Energetic Criteria

More to be added…

BACQ: Aggregation of the metrics into high-level operational indicators

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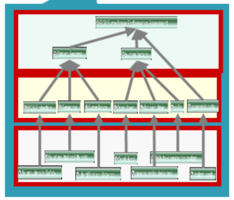
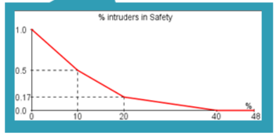
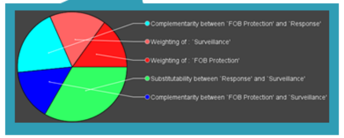
- Overall evaluation
  - Analytical N-Body
    - Q-score Many-Body
    - Many-Body Fidelity
  - Optimization (MaxCut, HOBO, S-Path)
    - Q-score MaxCut
    - Accuracy indexed by noise level
    - Probability of obtaining the optimum
  - Linear systems Solving (sparse/Dense matrix)
    - Accuracy indexed by noise level
    - Probability of solving the Problem
    - Algorithm-dependant Energetic criteria
  - Factorization
    - Probability to factorize
    - Size in Qubit of the calculated number

Problem Formalization: Metrics identification → Metrics normalization → Metrics aggregation

Performance assessment: Notation elaboration → Notation explanation







With Choquet integral

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- **Aggregates** all the metrics into a unique score (allowing ranking the solutions)
- Takes into account: the **interacting metrics**
  the **user preferences**
- Fully **interpretable** and **explainable**

EVIDEN

LNE THALES EVIDEN an atos business cea cnrs Teratec

BACQ Project Overview – See Article for Details

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BACQ - Application-oriented Benchmarks for Quantum Computing

Delivering an application-oriented benchmark suite for objective multi-criteria evaluation of quantum computing performance, a key to industrial uses

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***Abstract*—With the support of the national program on measurements, standards, and evaluation of quantum technologies MetriQs-France, a part of the French national quantum strategy, the BACQ project is dedicated to application-oriented benchmarks for quantum computing. The consortium gathering THALES, EVIDEN, an Atos business, CEA, CNRS, TERATEC, and LNE aims at establishing performance evaluation criteria of reference, meaningful for industry users.**

***Keywords*—Quantum Computer, Quantum Algorithm, Quantum Emulator, Quantum Annealer, NISQ, FTQC, Benchmark, Multi-Criteria Decision**

I. INTRODUCTION

Quantum computing promises to revolutionize multiple technical fields and activity sectors, from optimization in logistics, to simulation for research in physics or chemistry, engineering or industry, passing through cryptography. Measuring the progress towards the quantum advantage and the realization of such promises, with objectivity and reliability, is of high interest for potential end-users and crucial for the future development of the domain, now subject of hype and high competition. The challenges, especially to achieve comparable measurements, comes from the diversity of the hardware platforms, their specificities in terms of physical characteristics and applications, their maturity that can still be low, and the potential rapid evolution of the technologies.

A number of initiatives exist to benchmark the performance of quantum computers. Examples include Quantum VOLUME [1] and CLOPS [2] from IBM, SupermarQ [3] from Super-Tech or Quantum LINPACK- [4] from Berkeley Lab. The metrics used in these previous approaches are very technical and require familiarity with the technology. They therefore do not make it possible to derive operational indicators of the performance of the different families of algorithms executed on the different existing quantum computers. Dedicated to the whole value chain setting up from quantum hardware development to industrial

https://arxiv.org/abs/2403.12205
ArXiv [quant-ph], 14 pages

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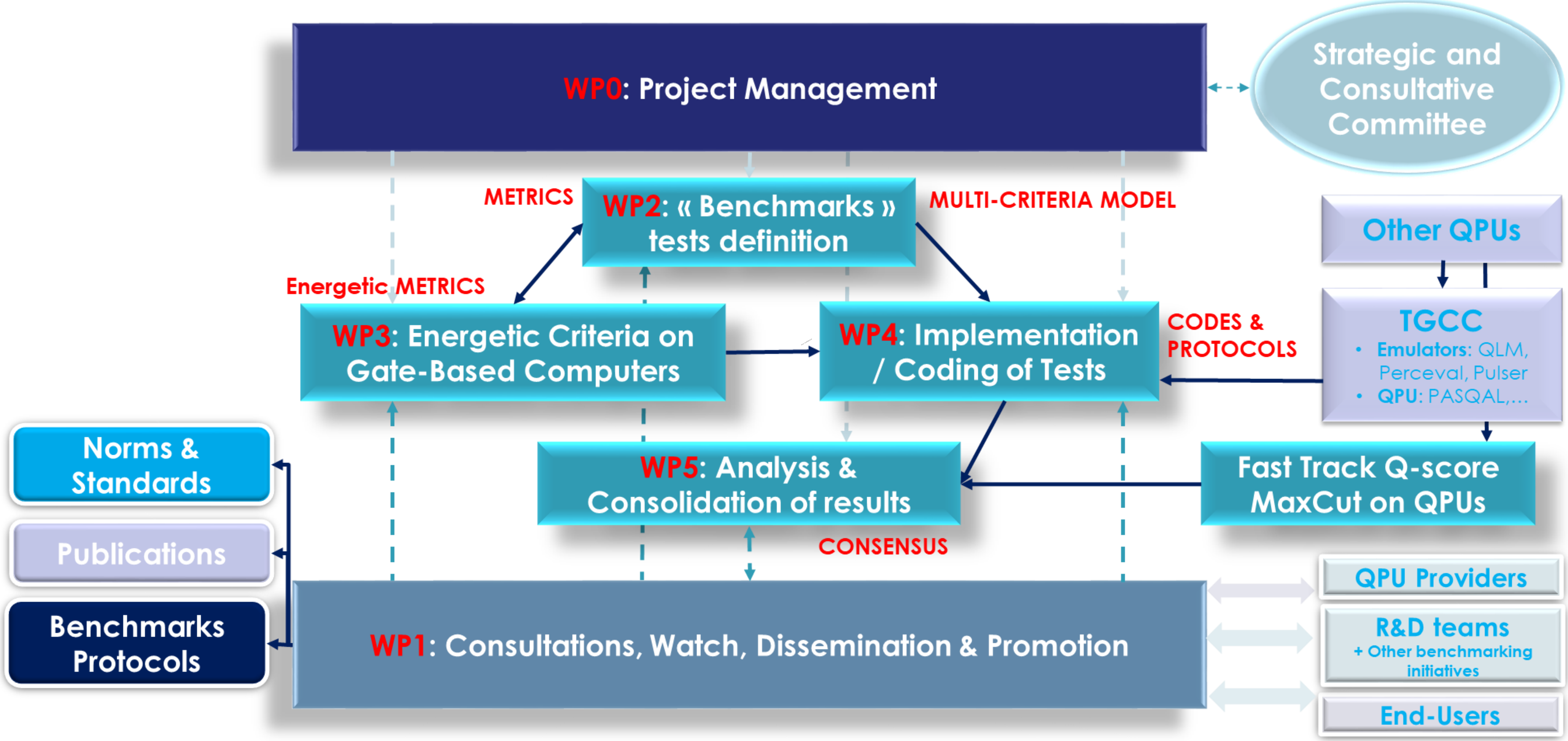
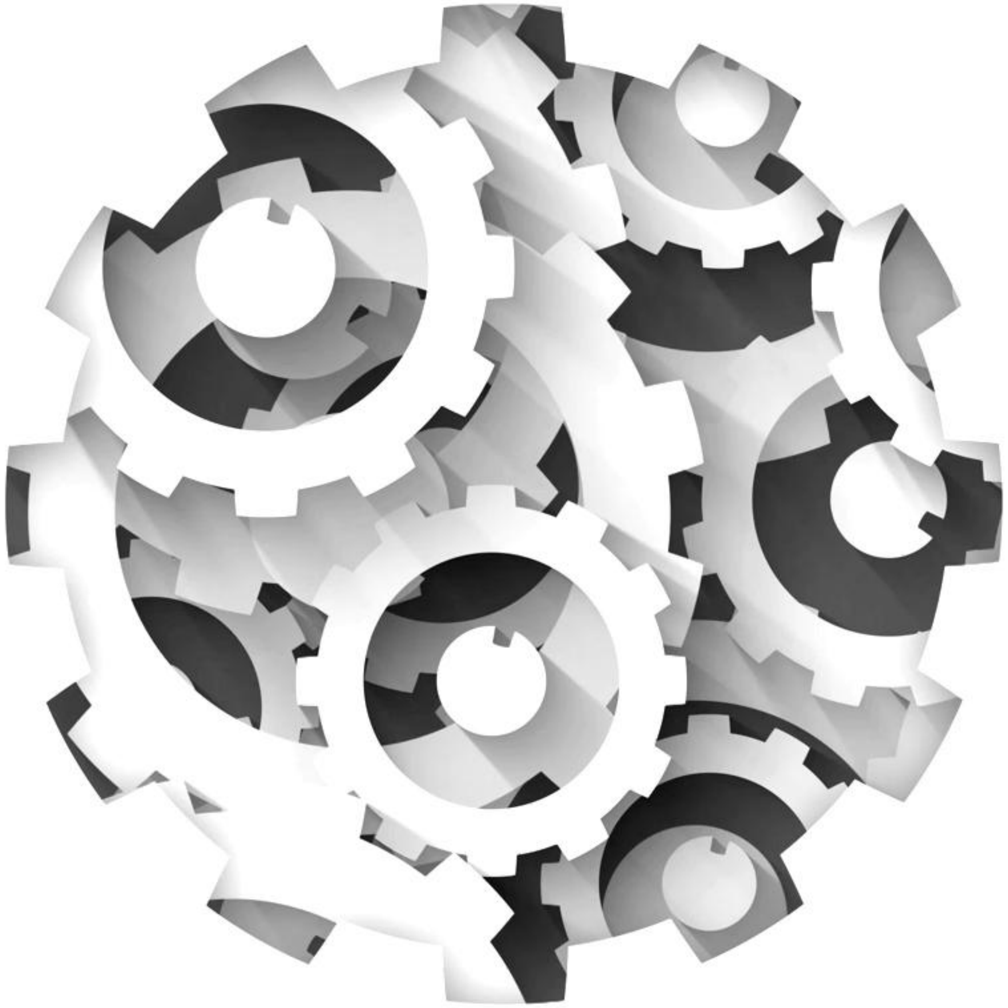
02 First Insights into BACQ Metrics

BACQ: Work Break Structure



Optimization



BACQ: Metrics elaboration

❖ *Optimization*

- Motivation and applications for optimization problems:
  - o **Proven quadratic advantage** (in propagation) in comparison to classical algorithms
  - o **Scalability** of the algorithm
  - o **Predictable** behavior and **susceptible to noise/errors**
  - o Diverse applications

A quantum walk assisted approximate algorithm for bounded NP optimisation problems

S. Marsh* and J. B. Wang†
School of Physics, University of Western Australia
(Dated: April 27, 2018)

Abstract
This paper describes an application of the Quantum Approximate Optimisation Algorithm (QAOA) to efficiently find approximate solutions for computational problems contained in the polynomially bounded NP optimisation complexity class (NPO PB). We consider a generalisation of the QAOA state evolution to alternating quantum walks and solution-quality-dependent phase shifts, and use the quantum walks to integrate the problem constraints of NPO problems. We apply the recent concept of a hybrid quantum-classical variational scheme to attempt finding the highest expectation value, which contains a high-quality solution. The algorithm is applied to the problem of minimum vertex cover, showing promising results using only a fixed and low number of optimisation parameters.

...4.08227v2 [quant-ph] 26 Apr 2018

PHYSICAL REVIEW RESEARCH 2, 023302 (2020)

Combinatorial optimization via highly efficient quantum walks

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(Received 6 February 2020; accepted 22 April 2020; published 8 June 2020)

We present a highly efficient quantum circuit for performing continuous time quantum walks (CTQWs) over an exponentially large set of combinatorial objects, provided that the objects can be indexed efficiently. CTQWs form the core mixing operation of a generalized version of the quantum approximate optimization algorithm, which works by "steering" the quantum amplitude into high-quality solutions. The efficient quantum circuit holds the promise of finding high-quality solutions to certain classes of NP-hard combinatorial problems such as the Travelling Salesman Problem, maximum set splitting, graph partitioning, and lattice path optimization.

DOI: 10.1103/PhysRevResearch.2.023302

I. INTRODUCTION

Combinatorial optimization problems are known to be notoriously difficult to solve, even approximately in general [1]. Quantum algorithms are able to solve these problems more efficiently, with a brute force quantum search offering a guaranteed square root speedup over the classical approach [2,3]. Such a speedup is, unfortunately, insufficient to provide practically useful solutions, since these combinatorial optimization problems scale up exponentially.

Farhi *et al.* [4] proposed the quantum approximate optimization algorithm (QAOA), derived from approximating the quantum adiabatic algorithm on a gate model quantum computer, to find high-quality solutions for general combinatorial optimization problems [4]. More recently, we extended the QAOA algorithm to solve constrained combinatorial optimization problems via alternating continuous-time quantum walks over efficiently identifiable feasible solutions and

and quantum information processing [14–25]. CTQWs are particularly well known for their applications to quantum spatial search [11,26,27], where the system is evolved for a sufficient length of time under the addition of the graph Hamiltonian A and an oracular Hamiltonian encoding the marked element(s). However, in QWOA we apply CTQWs independently, where a quantum circuit for $U(t) = e^{-itA}$ is used to map some initial amplitude distribution over the vertices to the distribution obtained after "walking" for time t. The oracular Hamiltonian encoding solution qualities are then applied sequentially, interleaved with further CTQWs. Of significance is that, for the graph structures considered in this paper, the runtime of a QWOA circuit can be made independent of the walk times, leading to a distinct algorithmic advantage.

In this paper, we discuss a significant and innovative application of QWOA to a wide range of combinatorial do-

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Quantum Walk-Based Vehicle Routing Optimisation

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This paper demonstrates the applicability of the Quantum Walk-based Optimisation Algorithm (QWOA) to the Capacitated Vehicle Routing Problem (CVRP). Efficient algorithms are developed for the indexing and unindexing of the solution space and for implementing the required alternating phase-walk unitaries, which are the core components of QWOA. Results of numerical simulation demonstrate that the QWOA is capable of producing convergence to near-optimal solutions for a randomly generated eight location CVRP. Preparation of the amplified quantum state in this example problem is demonstrated to produce higher-quality solutions than expected from classical random sampling of equivalent computational effort.

Keywords: quantum walk, quantum optimization, QWOA, quantum circuit, quantum computing

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I INTRODUCTION

Quantum computers may offer a unique advantage when it comes to many combinatorial optimisation problems, where the search for an optimal solution becomes quickly infeasible due

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Experimental implementation of quantum-walk-based portfolio optimization

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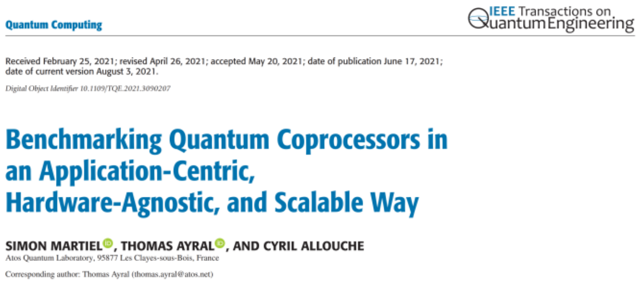
Keywords: quantum algorithms, quantum walk, portfolio optimization

Abstract
The application of quantum algorithms has attracted much attention as it holds the promise of solving practical problems that are intractable to classical algorithms. One such application is the recent development of a quantum-walk-based optimization algorithm approach to portfolio optimization under the modern portfolio theory framework. In this paper, we demonstrate an experimental realization of the alternating phase-shift and continuous-time quantum walk unitaries that underpin this quantum algorithm using optical networks and single photons. The experimental analysis confirms that the probability of states corresponding to high-quality solutions is efficiently amplified by increasing the number of phase-shift and quantum walk iterations. This work provides strong evidence for practical applications of quantum-walk-based algorithms such as financial portfolio optimization.

Q-score: A Broader View

- **Why Q-score Matters?**
  - Current quantum metrics often miss the mark on real-world relevance.
  - Q-score fills the gap by evaluating quantum systems based on their ability to solve problems like Max-Cut
  - Applications: Circuit design, Data clustering, Network optimization
  - Hardware-agnostic, scalable across platforms
  - Q-score allows comparison of the true performances of various QPUs
- **Application-Centric Benchmarking**
  - Focuses on practical performance, not just hardware specs
  - Reflects how well quantum processors handle optimization tasks that matter to industry
  - Single number metric: maximum graph size (n) solvable above threshold
  - Application-driven metrics like Q-score provide transparency and guide users and manufacturers
- **Versatile & Scalable**
  - Q-score methodology covers not only gate-based QPUs but also analog simulators and quantum annealers
  - Adapts to evolving quantum platforms and algorithms

Quantifies the performances of quantum devices in solving combinatorial problems


Quantum Computing

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Benchmarking Quantum Coprocessors in an Application-Centric, Hardware-Agnostic, and Scalable Way

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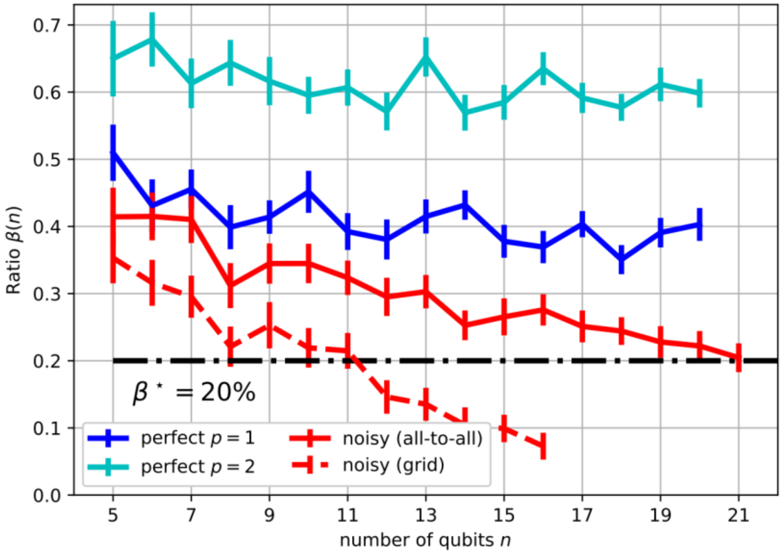
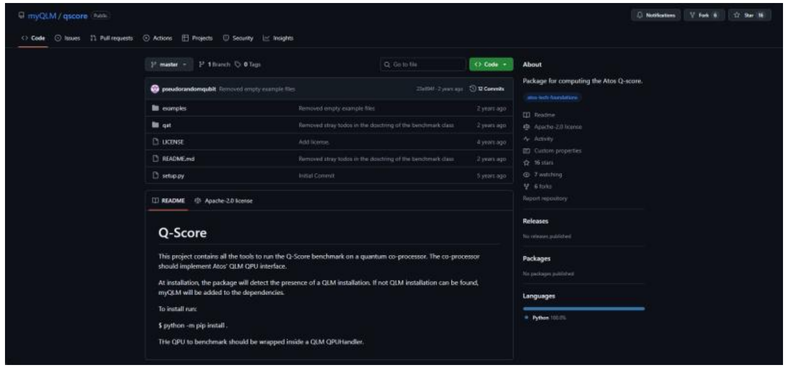
Understanding Quantum Benchmarks with Q-score Max-Cut

- **Q-score Highlights:**
  - Q-Score is associated with the effective number of qubits that a specific quantum stack comprising both quantum hardware and optimization software such as compilers can utilize to solve a combinatorial optimization problem known as the Maximum Cut problem
  - Q-score, introduced by Atos in 2021
- **Max-Cut & QAOA:**
  - Based on Max-Cut optimization problem: Max-Cut = partitioning graph nodes into 2 sets, maximizing edges across the cut
  - Typically implemented with QAOA (but adaptable: VQE, etc.)
  - QAOA: uses parameterized quantum circuits optimized by classical algorithms
- **Future Prospects:**
  - Expect more Q-score like variants for different use cases beyond optimization problems
  - Collaboration with international scientists and QPU manufacturers to refine the Q-score family, deepen partnerships, and improve QPU integration
  - Q-score maturity and its widespread adoption open the door to discussions about benchmarking standardization
  - Already implemented by several QPU providers



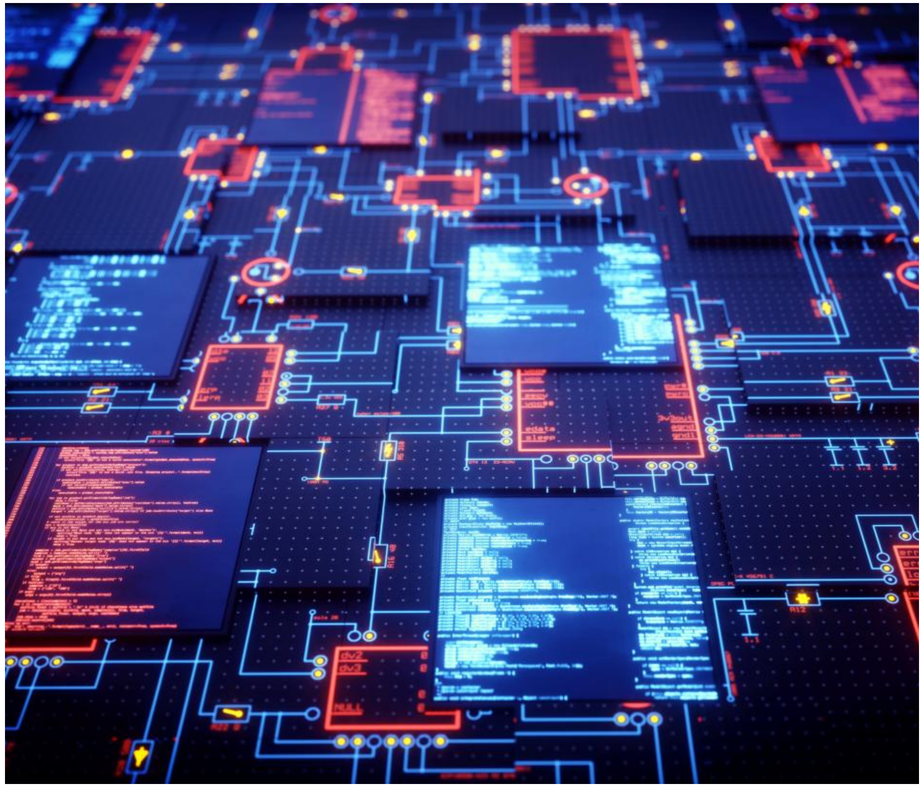


Download open-source code:
https://github.com/myQLM/qscore

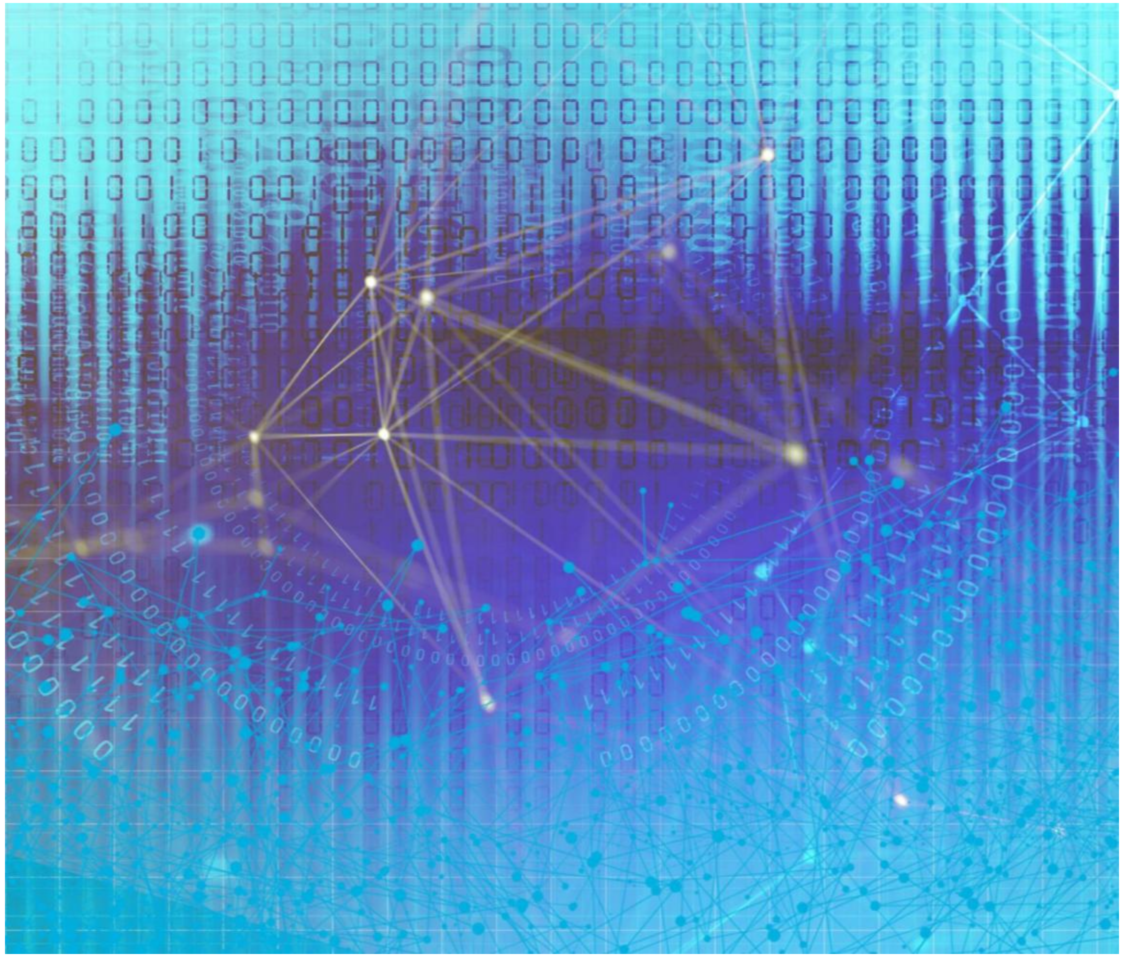
Q-score definition & Interpretation

$$\beta(n) = \frac{C(N) - C_{rand}}{C_{max} - C_{rand}}$$

- **Q-score Protocol**
  - 1. Select graph size n
  - 2. Generate 100 random Erdős–Rényi graphs
  - 3. Run QAOA (depth p=1, COBYLA optimizer)
  - 4. Measure performance via β(n) (relative to random guessing and exact solution)
  - 5. Q-score = largest n where β(n) > threshold
- **Interpretation**
  - More than a number: scaling β(n), effect of noise, full Quantum stack benchmarking
  - Reflects full stack performance (hardware + software)
  - Continuous improvement: Q-scores expected to rise as qubit quality improves



G-Score (Max Cardinality Matching)



- **Max Cardinality Matching**

  The largest set of pairs that don't overlap

- **Definition of G-Score**

  G-Score combines success probability and solution optimality to benchmark quantum optimization performance.

- **Application on Quantum Systems**

  G-Score evaluates quantum annealers like D-Wave by measuring accuracy and reliability in solving MCM problems.

- **Complement to Other Metrics**

  G-Score complements Q-Score by focusing on constrained problems and providing detailed performance insights.

MIS Optimization Benchmark

- **MIS:**
  The largest set of nodes that are not connected to each other.

- **Purpose of MIS Benchmark**
  Evaluates quantum systems' ability to solve difficult combinatorial optimization problems effectively.

- **Key Performance Metrics**
  Measures ratio of largest sampled independent set to true MIS and probability of single-shot solution sampling.

- **Relevance and Impact**
  Helps identify quantum advantage potentials and guides hardware development for solution quality and reliability.

- **Complementary Benchmarks**
  MIS benchmark complements Q-Score and G-Score by focusing on constrained, application-specific quantum performance.

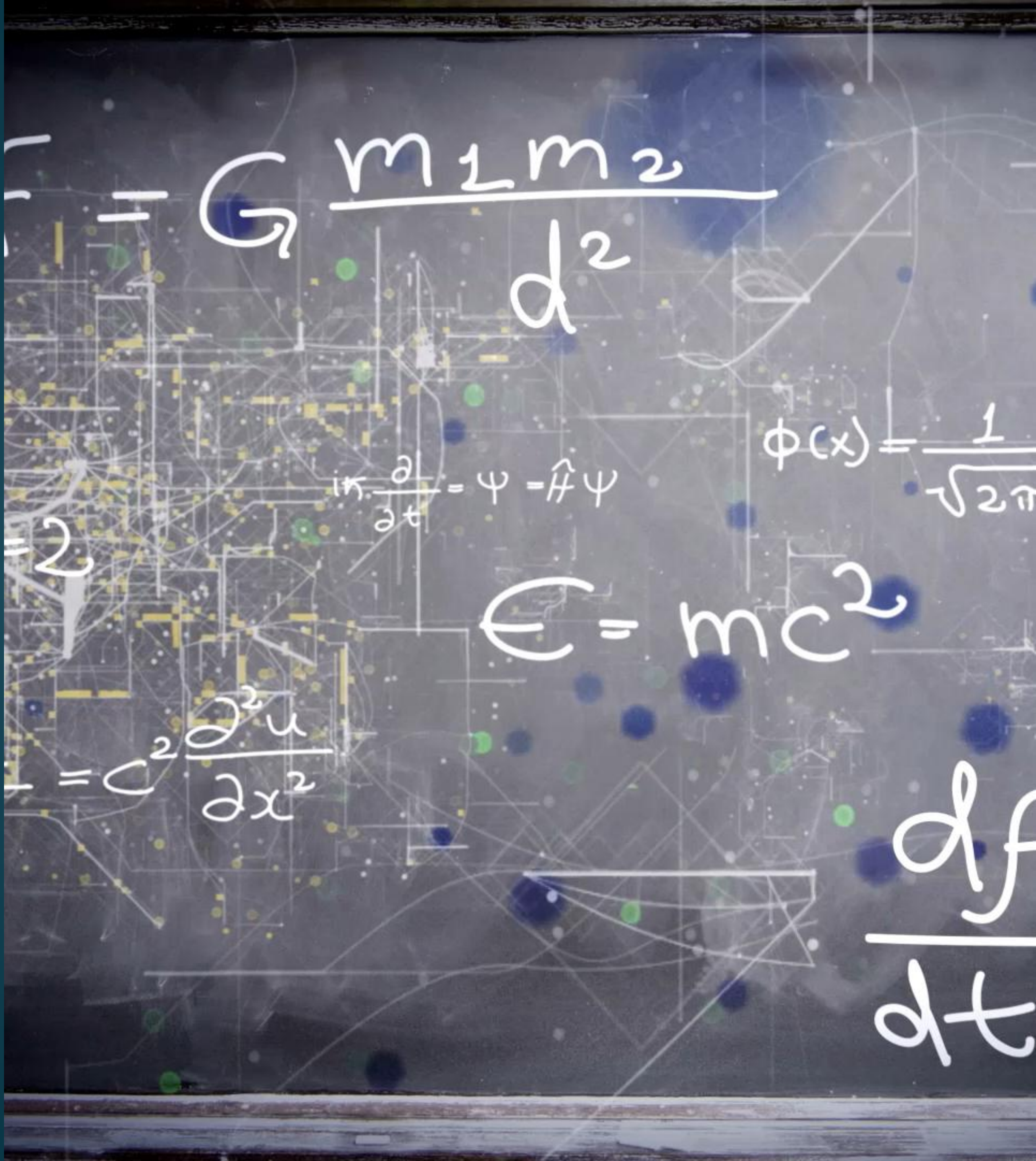
Graph Pathfinding Problem

- **Objective:**

  Find a destination node from a source node in a graph with high success probability

- **Goals:**
  - Highlight hardware progress to leverage promising quantum routines for optimization applications
  - Focus on Quantum Walks and Amplitude Amplification

Physics Simulation



BACQ: Metrics development

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Simulation of Quantum Physics Models

- **Why ?**

  Quantum physics problems with **many interacting particles** arise in various fields of science:

  - - solid-state physics (superconductivity, correlated electrons, quantum magnetism, electronic transport, understanding new quantum phenomena & design of new materials with potential applications)
  - - chemistry (electronic structure of molecules, elucidating chemical reactions, catalyst design, …)
  - - high-energy physics (particle or nuclear physics, gauge theories)

  …

  Simulating these quantum many-body systems is notoriously difficult on a classical computer

- **Goal**
  - Develop metrics to quantify the capacity of a quantum machine **to simulate accurately** physically relevant quantum many-body problems

- **Method**
  - - Target non-trivial **many-qubit entangled states**
  - - Focus on many-body problems/states/Hamiltonians which are **exactly solvable**

    (to allow for comparison between the theoretical [error-free] results and the measured ones)

BACQ: Metrics development

Simulation of Quantum Physics Models

- **Models & Architectures**
  - BCS model
  - **Gate-based** quantum computers

$$\mathcal{H}_{\mathrm{BCS}} = -\sum_{j=0}^{L-1}\left(\epsilon_j - \frac{g}{2}\right)\sigma_j^z - \frac{g}{2}\sum_{0\leqslant i<j\leqslant L-1}\left(\sigma_i^x\sigma_j^x + \sigma_i^y\sigma_j^y\right),$$

- **Metrics development** *(by CEA/DRF)*
  - ***All-to-all coupling*** (challenging and probes connectivity)
  - Exact theoretical ***solution is available***
  - Compare dynamics simulation on a quantum computer with exact results
  - ***Cascade of error-mitigation techniques*** allows estimating the ***significance of different error types*** (local errors vs crosstalk)
  - gives insight about error sources

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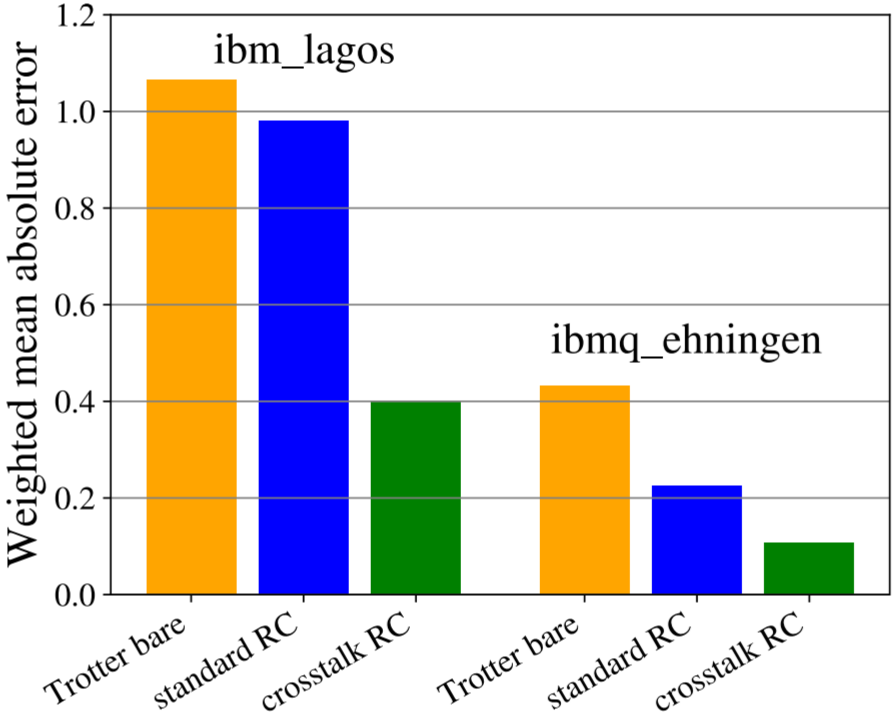

MBQS (Many-Body Quantum Score)

- **Benchmarking Protocol**

  MBQS is a benchmarking protocol for analog quantum processing units evaluating many-body quantum dynamics simulation accuracy.

- **Measurement and Calculation**

  The protocol measures two-point correlation functions and calculates average relative errors between theory and experiment.

- **Scalability and Fidelity**

  MBQS score indicates the largest system size with errors below a threshold, assessing QPU scalability and fidelity.

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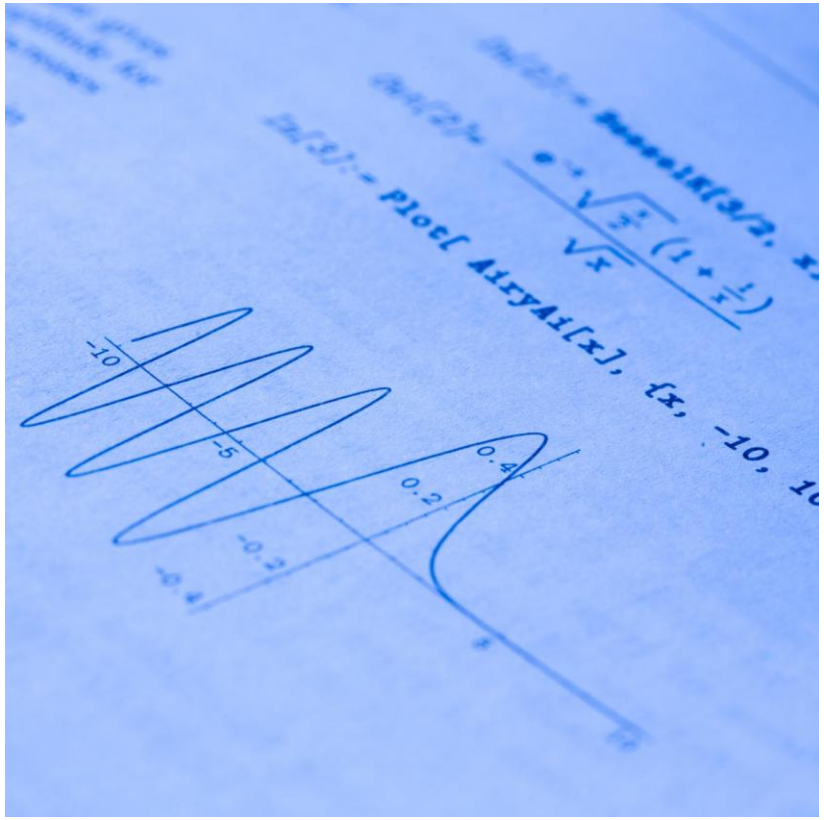
Linear Systems Solving

Linear System Solving (LSS)



LSS Benchmark Purpose

LSS benchmark evaluates quantum annealers by solving Ax = b using least squares in a QUBO format.

Performance Measurement

Success probability versus variables and resolution is measured and fitted using a sigmoid function.

Quantum Processing Unit Capability

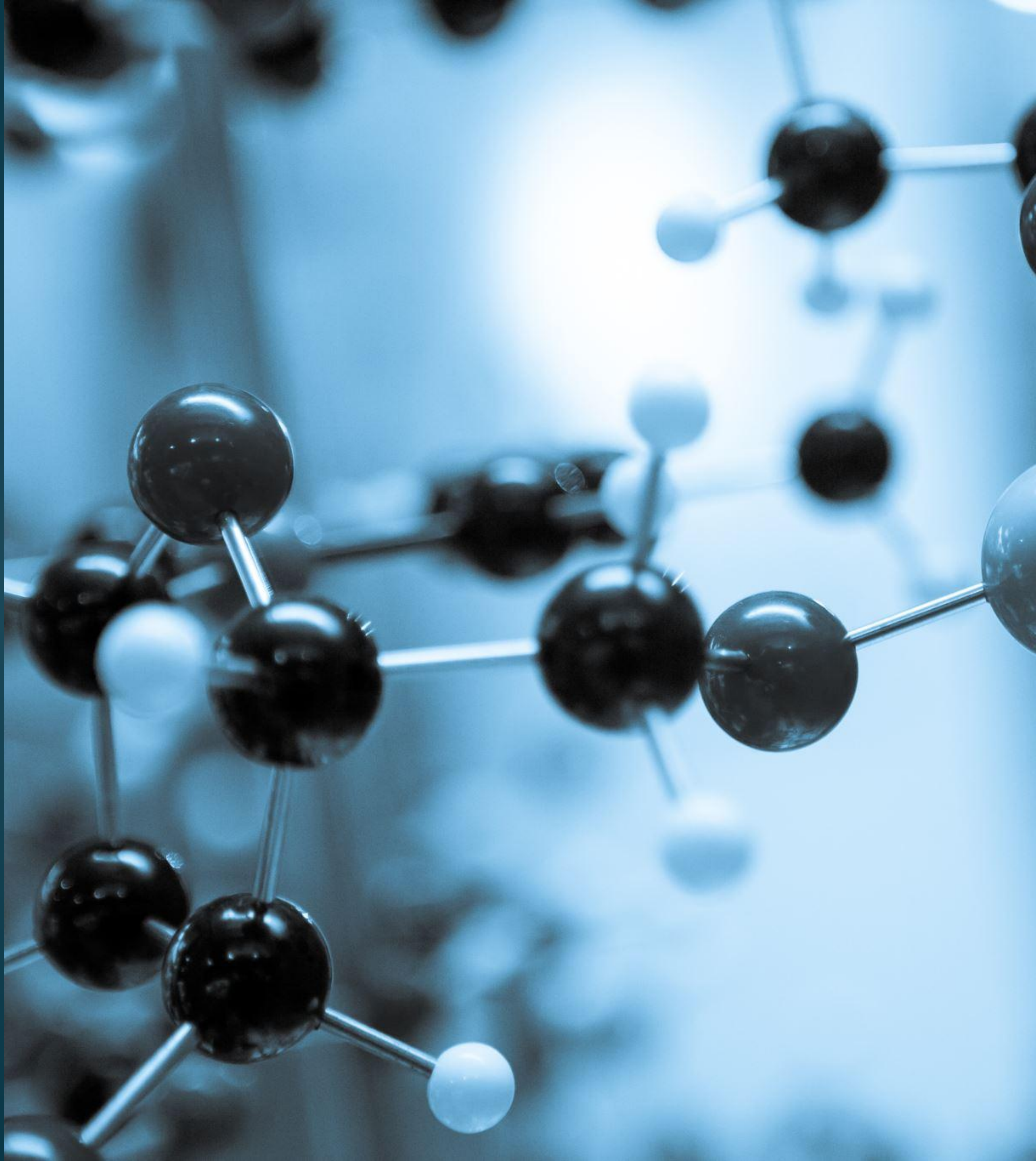
The inflection point of the sigmoid curve indicates QPU capability.

Practical Insights and Challenges

LSS benchmark reveals quantum system utility in simulations and challenges in scalability and precision.

EVIDEN

Prime factorization

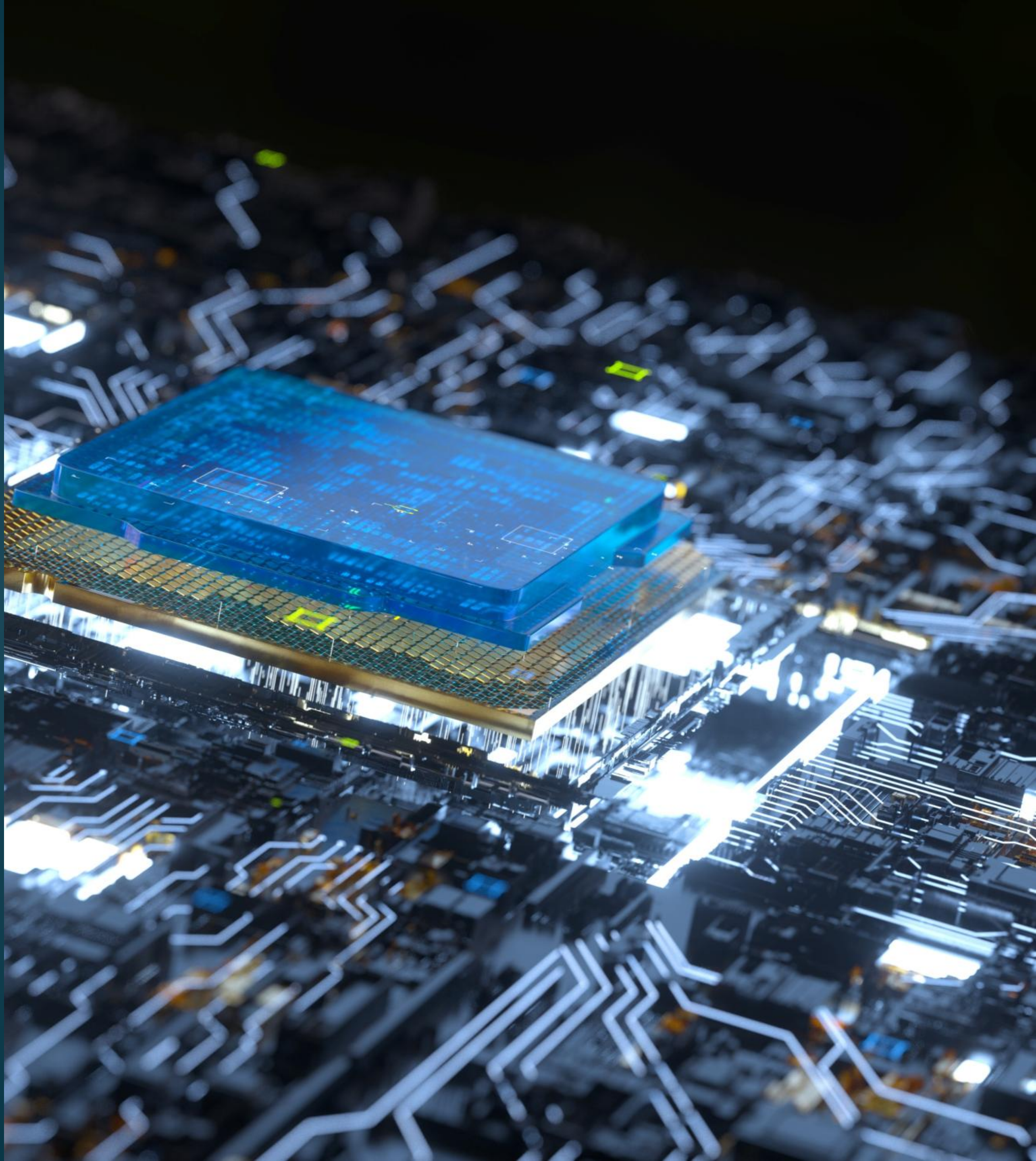


BACQ: Prime factorization

- **(Hamiltonian-based) integer factorization**
  - Idea: Develop metrics to evaluate the capabilities of quantum computers on **prime factorization**
    - Prime factorization is a very hyped potential utilization of QC
    - Make it work on gate-based and analog QC
    - Shor's algorithm will not work before FTQC
    - Once FTQCs are available, we can still use this first method 1) for analog 2) as a base of HOBO problem
  - Metrics:
    - **Probability of finding the optimum** or distance to optimum/solution
    - **Size of the problem**
    - **Complexity and sparsity of the problem**
    - **Complexity of pre/post processing if required**

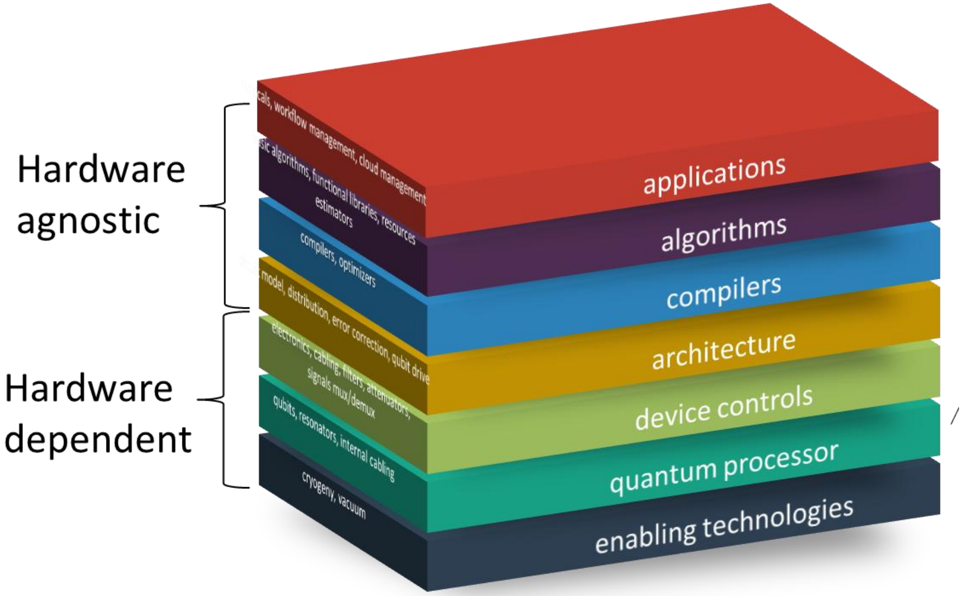
EVIDEN

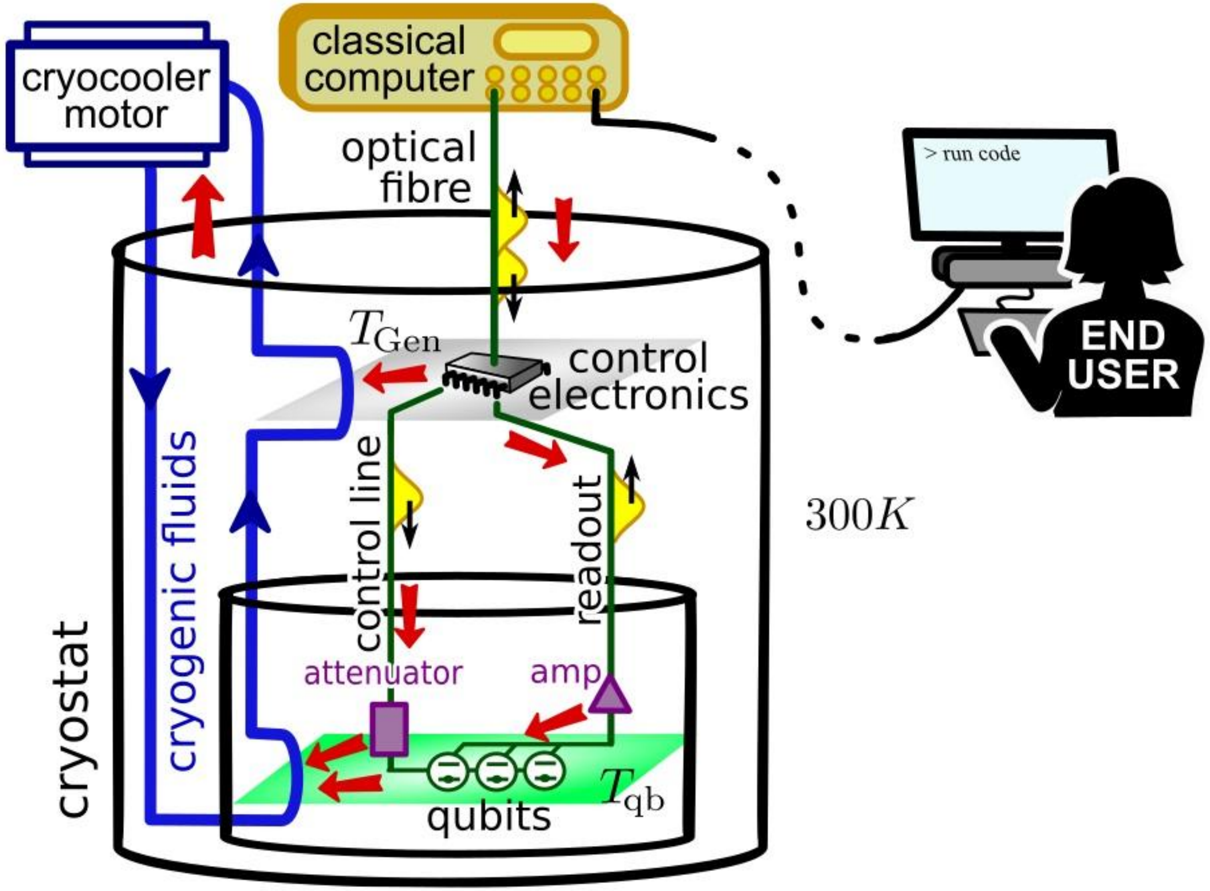
Energetic critera



BACQ: Metrics elaboration - Energetics

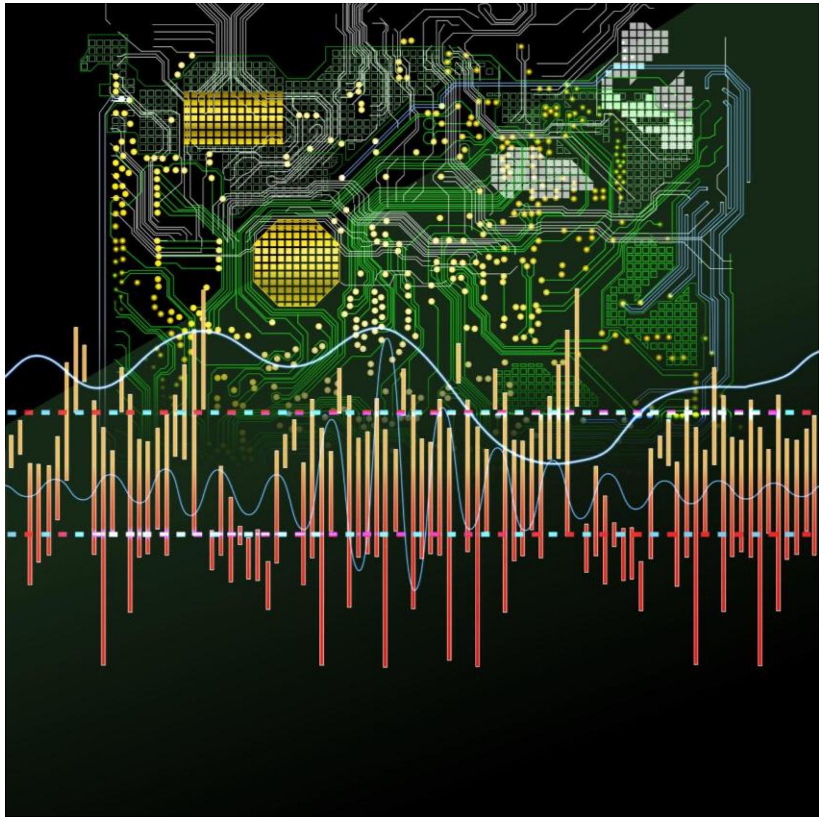
- **Defining Resource Efficiency as the ratio of Performance Metrics / Resource Cost**





In BACQ, focus on resources at the HW-agnostic layers for linear system solving, with test on a gate-based machine

MNR Framework (Metric–Noise–Resource)



Comprehensive Quantum Evaluation

MNR framework evaluates quantum systems across computational layers using key performance and noise metrics.

Performance and Resource Trade-offs

The framework highlights trade-offs between performance metrics and resources, focusing on energy efficiency.

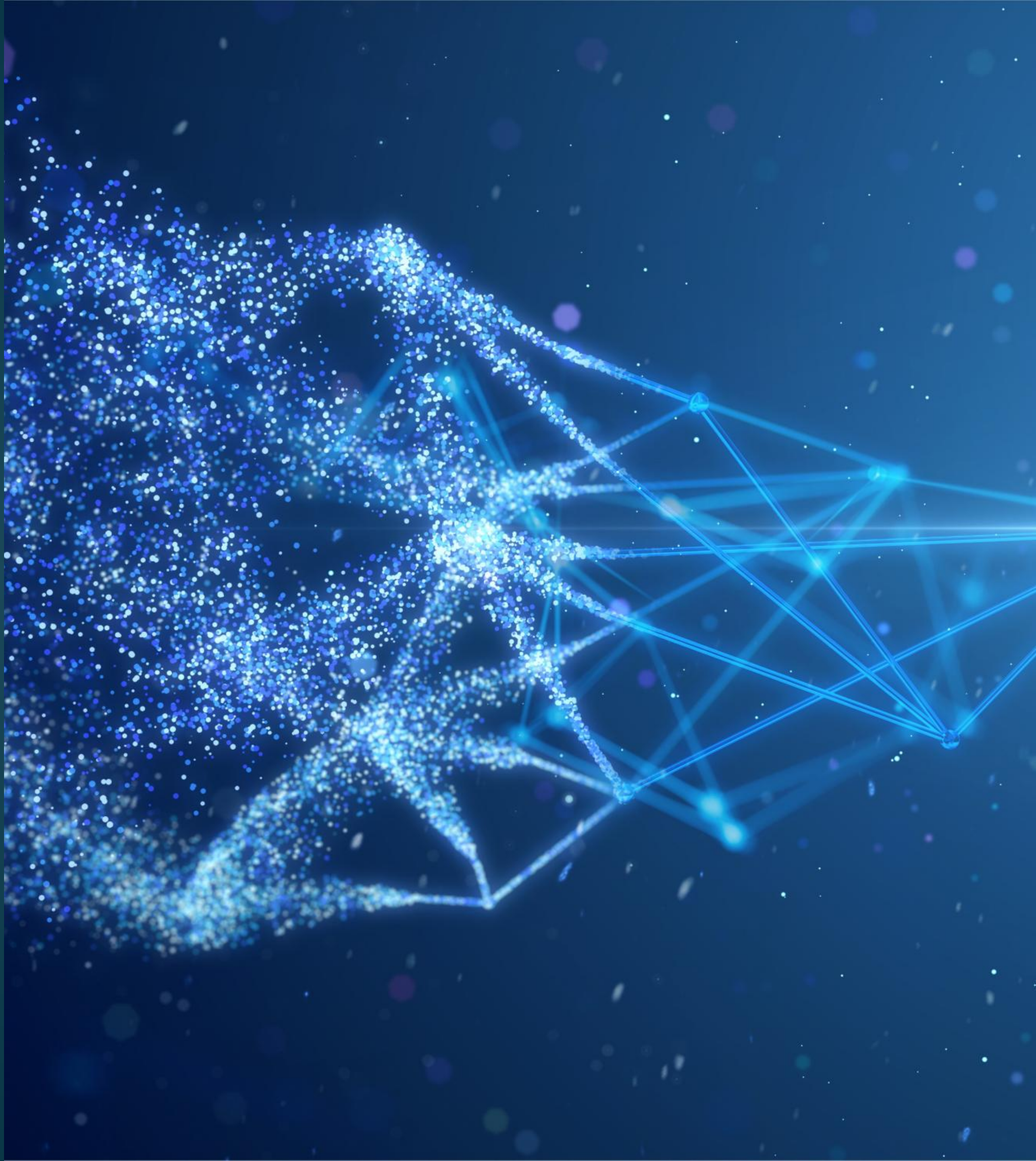
Application to Quantum Algorithms

MNR guides quantum algorithm optimization, exemplified by the Variational Quantum Eigensolver under noise.

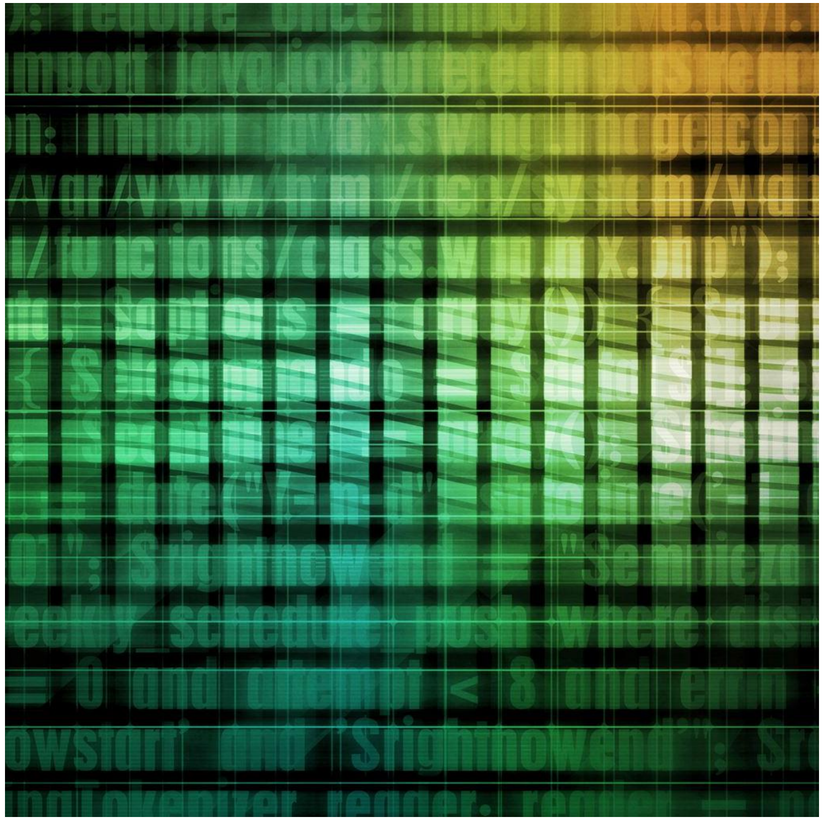
Standardization and Benchmarking

MNR supports benchmarking and standardization across diverse quantum computing technologies.

Aggregation & Q-MYRIAD



Q-MYRIAD Aggregation Framework



Multi-Criteria Benchmark Aggregation

Q-MYRIAD combines diverse quantum benchmarking KPIs into a unified evaluation framework using normalization methods.

Utility Functions and Normalization

The framework applies utility functions and satisfaction scales to normalize KPIs with defined reference levels and thresholds.

Comparative QPU Analysis

Aggregated scores enable transparent comparison and informed decision-making across different quantum processing units.

Interoperability and Standardization

Q-MYRIAD supports integration of benchmarking data from diverse sources, promoting interoperability in quantum evaluation.

MYRIAD-Q: multi-criteria approach for quantum benchmarking

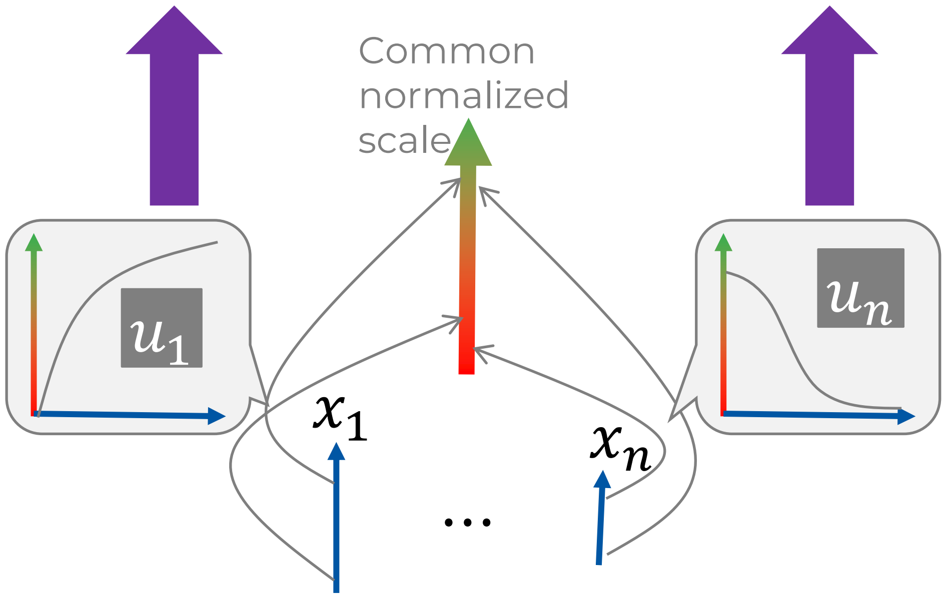
BACQ
MetriQs-France

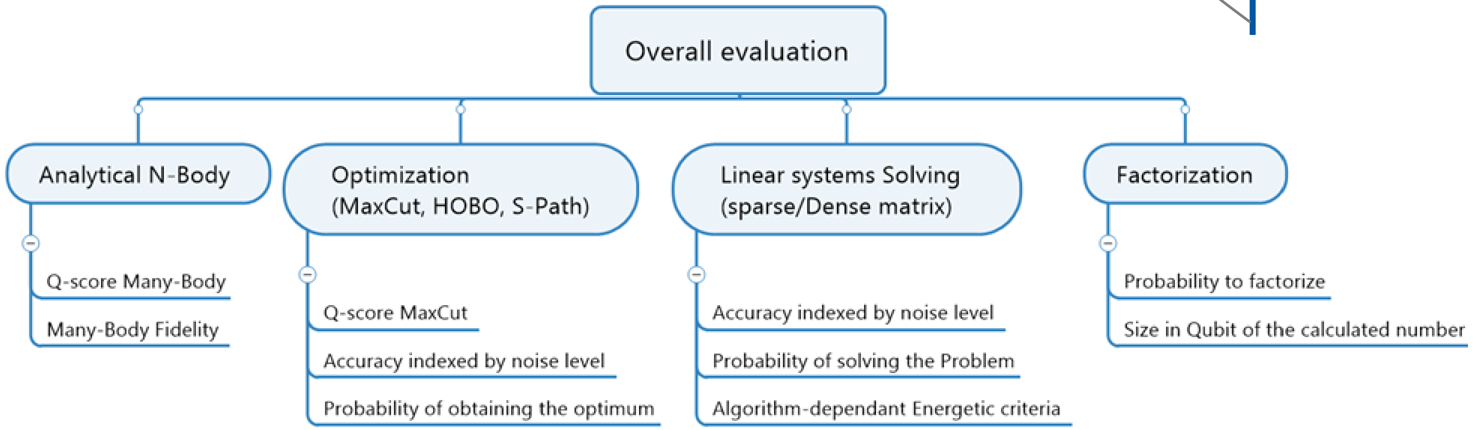
- **How to combine many metrics to assess/compare quantum solutions (QPU – algorithms)?**
  - Potentially many metrics from different benchmarking problems
  - Metrics are given in different units
  - Different priorities among metrics
- **Approach: use of Multi-Criteria Decision Support.**

2-step approach:

- Step 1: normalization of metrics
  - $x_i \mapsto u_i(x_i)$
  - Output = normalized score in $\mathbb{R}_+$
- Step 2: aggregation of normalized scores

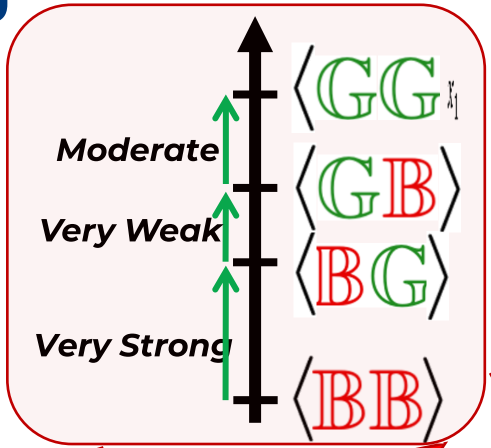
$$u(x) = H\big(u_1(x_1), \dots, u_n(x_n)\big)$$

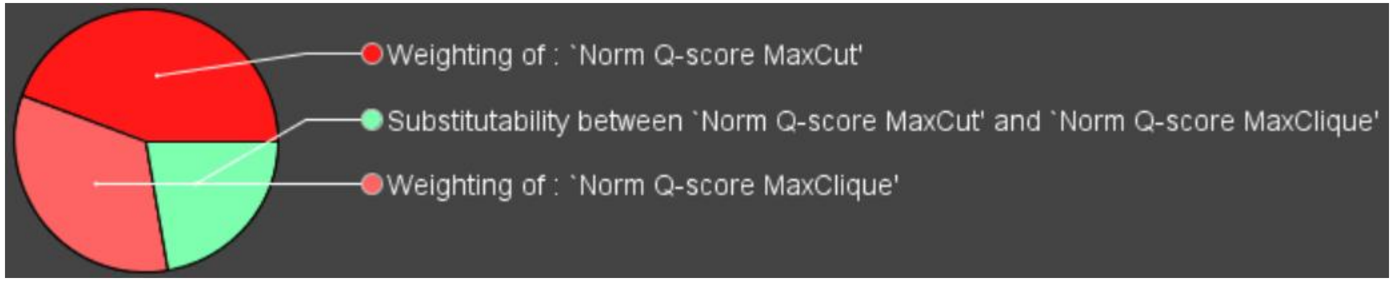




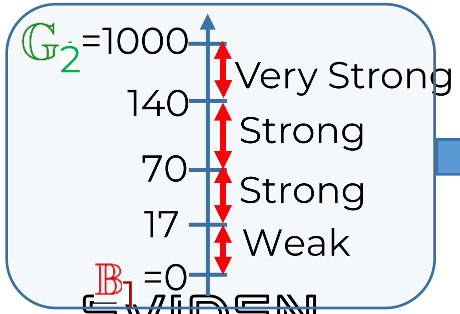
MYRIAD-Q: multi-criteria approach for quantum benchmarking

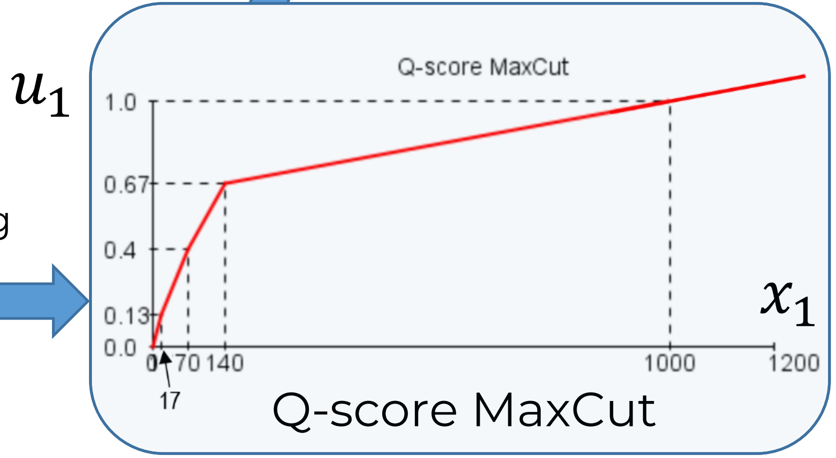
Illustration of the elicitation process with MYRIAD

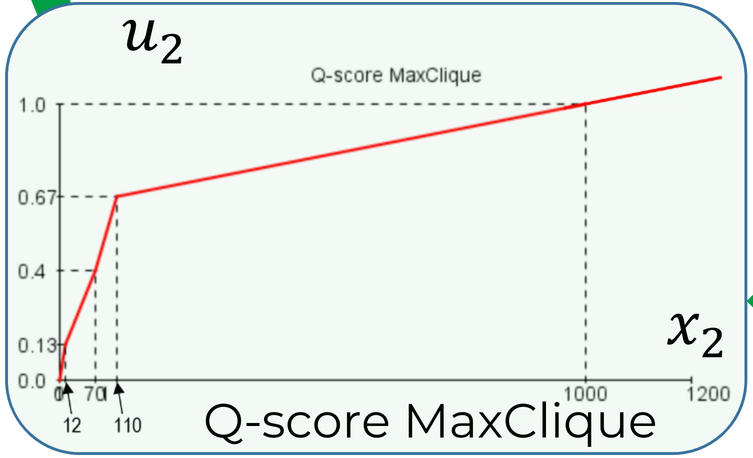


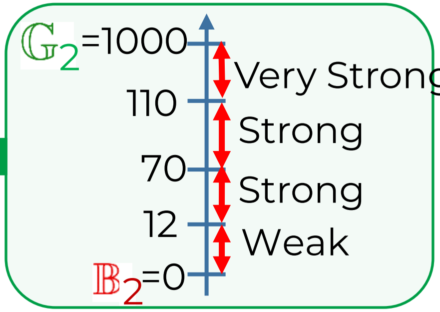


$$u(\mathbf{x}) = w_1 \underbrace{u_1(x_1)} + w_2 \underbrace{u_2(x_2)} + w_{1,2} \min\big(u_1(x_1), u_2(x_2)\big)$$









MetriQs-France: Standardization of QC benchmarks

MetriQs France

- **Towards globally harmonized and recognized benchmarks**

- At the European CEN-CENELEC JTC22 “Quantum technologies” / WG3 “Quantum computing & simulation”
- Ongoing standardization project on QC benchmarks started in Oct. 2023 with participation from FR, NL, UK, IT, AT, DE…

Document history
V0.0: 20231012, CEN-CENELEC TR template
V0.1: 20231012, First version of index

CEN/CLC/JTC 22

Date: 20YY-XX

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Secretariat: DIN

Quantum Technologies

Benchmarking quantum computers

- At the international IEC/ISO JTC3 “Quantum technologies”
- Ongoing preparation of a new standardization project on QC benchmarks (from HW-level to application-level and beyond) with FR, JP, UK, CA, AU, KR…

Wrapping Up

- ❖ BACQ delivers application-oriented benchmarks tailored to both gate-based and analog quantum computers, from NISQ to FTQC.
- ❖ Collaborative effort: six major French partners (Thales, Eviden, CEA, CNRS, Teratec, LNE) working together with QPU providers and EuroHPC infrastructures.
- ❖ Comprehensive benchmarking: covering optimization, physics simulation, linear systems solving, and factorization
- ❖ Complementary with low-level metrics:
- ❖ MYRIAD-Q framework enables multi-criteria aggregation of metrics, supporting transparent and interpretable QPU comparisons.
- ❖ BACQ bridges research and industry , paving the way toward standardized quantum performance evaluation.

Questions

Thank you!

For more information, please contact:

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Fast-track Initiative

- **Fast-Track Quantum Computing Benchmarking Initiative**
  - Part of BACQ project
  - A collaborative effort among quantum computing industry leaders
  - Objective: Conduct a comprehensive measurement campaign on existing QPUs using the Q-score metric
  - Significance: Marks a pivotal moment in quantum computing evaluation and benchmarking
- **Goals: Open & Broad Collaboration**
  - Collect practical feedback from QPU runs
  - Contribute to the development of standardized benchmarking protocols
  - Expand QPUs access
  - Enhance Exchange and Reciprocal Knowledge
- **Future and Impact**
  - Fast-Track stands as evidence of collaborative innovation in quantum computing
  - Advanced partnerships and open contributions to develop quantum computing benchmarks
  - Fast-Track's success leads to an extension of our tests, deepening our understanding of quantum computer benchmarking
  - Refining Q-score and Advancing Standardized Benchmarking Protocols

Q-score experimentation Campaign

Practical Implementation Overview

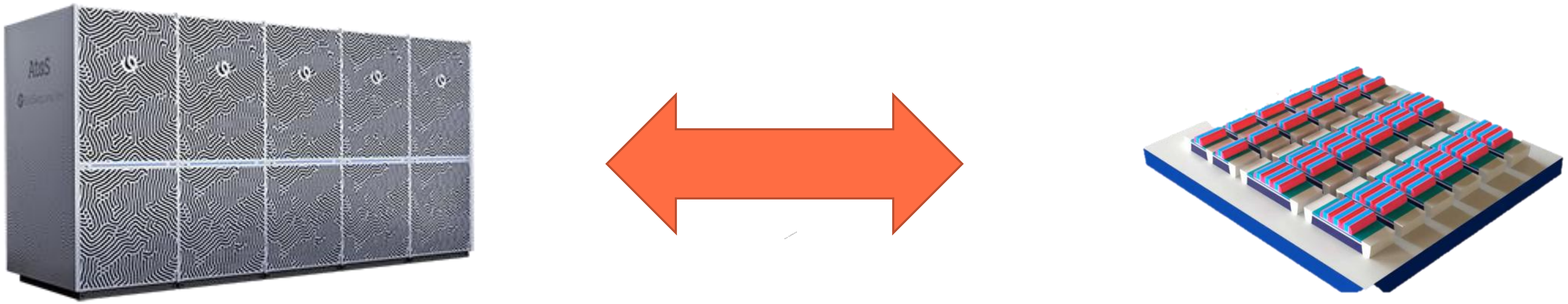
- **IQM:**
  - Qubit technology: 20 Superconducting qubits (Resonance)
  - Q-score/Max-Cut With QAOA
  - Q-score = 15
  - Reference: Teratec : Séminaires TQCI
- **Pasqal:**
  - Qubit technology: Neutral Atom
  - Q-score/Max-Cut with Maximum Independent Set (MIS)
  - Q-score: emulator only
  - Reference: arXiv:2207.13030
- **Quandela:**
  - Qubit technology: Photonic
  - Q-score/Max-Cut with Variational Quantum Eigensolver (VQE)
  - Q-score = 15
  - Reference: Teratec : Séminaires TQCI
- **D-wave made by TNO:**
  - Qubit technology: Superconducting quantum annealer
  - Q-score/Max-Cut implementation on D-wave (QUBO)
  - Q-score = 140 (D-wave Advantage)
  - Reference: arXiv:2208.07633

High-performance Computing & Quantum

How to harness the power of quantum in a HPC system?

Classical HPC:

Quantum chip:



Wanted:

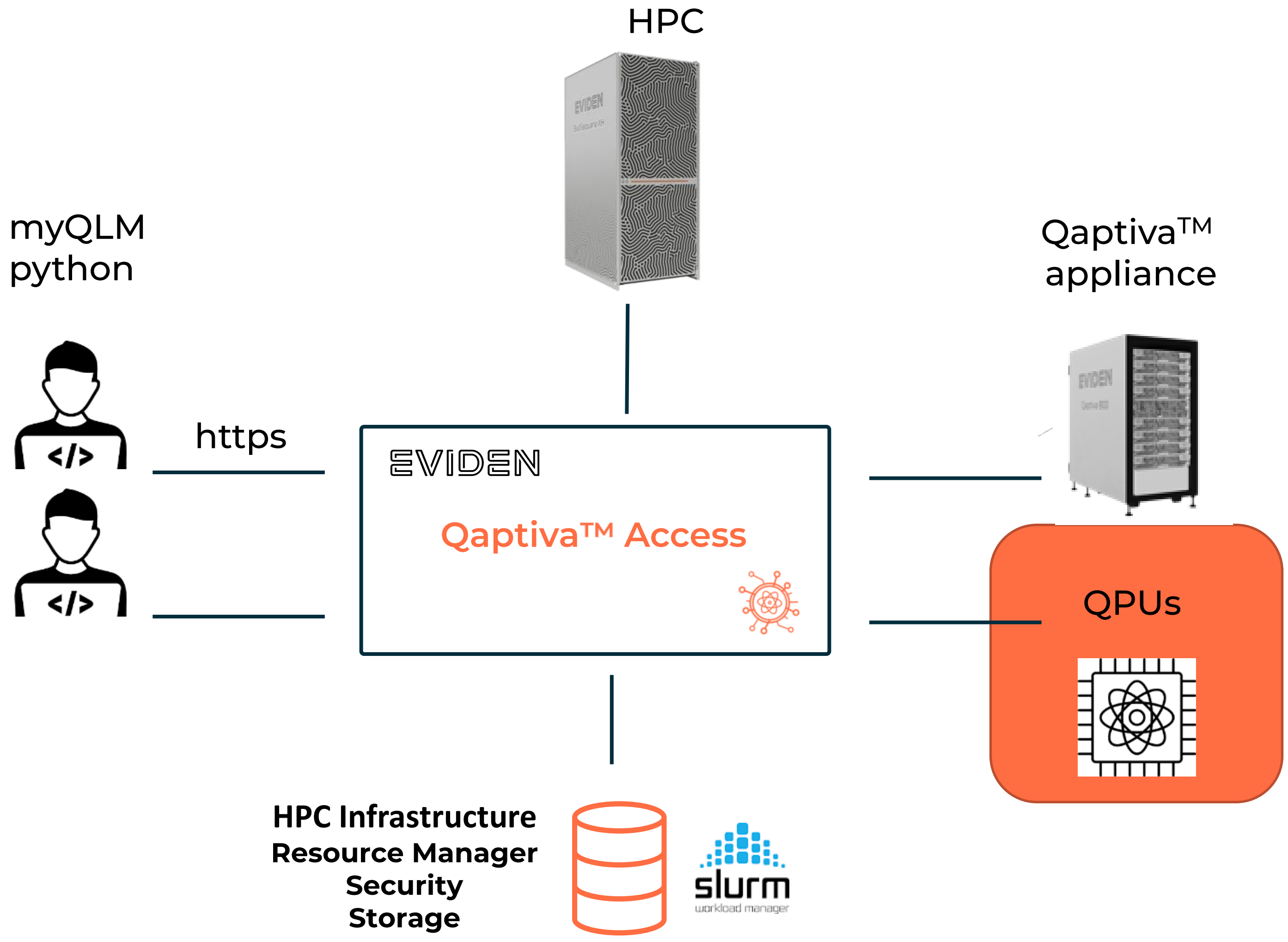
- Continue running large legacy classical codes
- Use hardware-agnostic quantum programming
- Benefit from resource scheduling (etc)

Constraints:

- Native quantum gateset
- Connectivity constraints
- Decoherence

Qaptiva™ Access

HPC & Quantum hybridization



Integration of any quantum processing unit (QPU) and emulator into the high-performance computing (HPC) infrastructure.

- Real scheduling of QPUs with SLURM
- Scale-out numerical simulation (MPI + GPU)
- Used in several HPC-QC pilots:
  - HPC-QS (EuroHPC)
  - HQI (France)
  - QSolid (GER)