Enabling the large scale quantum revolution

Large Scale Quantum for all

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QPerfect

Enabling the fault-tolerant quantum revolution

Company introduction & MIMIQ-CIRC product presentation

- Spin-off from research in Strasbourg, at the **European Center For Quantum Sciences (CESQ)**
- **Created** in May 2023
- **Awarded** the iLab grand prix in 2023
- Leveraging a strategic location at the hearth of Europe, situated at the border between France, Germany and Switzerland

Our MISSION

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Enabling the fault-tolerant quantum revolution

We develop software and hardware solutions to **help designing** quantum computers, **benchmark** algorithms, and **improving** existing quantum computers

Our developments

Large scale quantum circuit simulators

Simulate 100s of qubits
- **Faster** than widely used solutions;
- **Exactly**, for entanglement bound circuits;
- or with **higher fidelities** than any current NISQ hardware.

Virtual Quantum Computer toolbox for Design Automation
- **Fully customizable**: large library of devices and noise models;
- **Hardware accurate**: waveform level simulation of full QC setups

Hardware accurate simulation toolbox

Hardware optimized gate sets and algorithms

Fastest and **highest-fidelities** protocolst yet
- **Custom designed**: adapt to every need and platform;
- **Hardware-specialized**: exploit hardware features

MIMIQ: torwards an holistic Quantum Design Automation (QDA) tool

- **Developer tools for quantum computing**
- **Design** algorithms or virtual quantum processors
- **Evaluate** the performances of new ideas
- **Optimize** from hardware to application software

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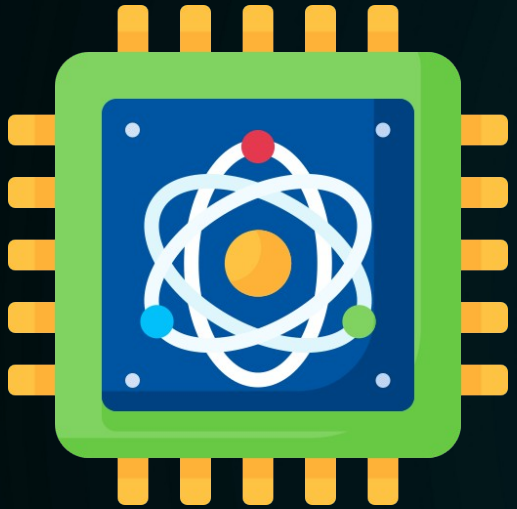

MIMIQ-CIRC

Virtual Quantum Computer

Design, simulate and optimize quantum software

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MIMIQ-CIRC:
universal quantum circuit simulator

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Universal — Execution of **arbitrary** quantum algorithms.

Fast — Up to 10 times faster than commonly used solutions.

Fast — Simulate circuits up to **100s of qubits!**
Exactly or approximately, depending on circuit complexity.

Accurate — High fidelity approximations.
Error rates below current state-of-the-art hardware.

Exponential Complexity

Simulating quantum systems is hard

$$|\psi\rangle \longrightarrow 2^N \textbf{ Complex Numbers}$$

On a Classical Computer

32 qubits	64 **GB** of RAM
40 qubits	16 **TB** of RAM
50 qubits	16 **PB** of RAM

Also time scales exponentially!

What we do in MIMIQ:

- Heavily optimized implementation (explicit SIMD).
- Circuit optimization and compression.
- Alternative techniques: Matrix Product States (MPS)

Real applications do not use the full state space

Restricted by noise, finite algorithm sizes, limited connectivity

Matrix Product States

Strasbourg Cathedral

Original | 50% compression ratio | 5% compression ratio

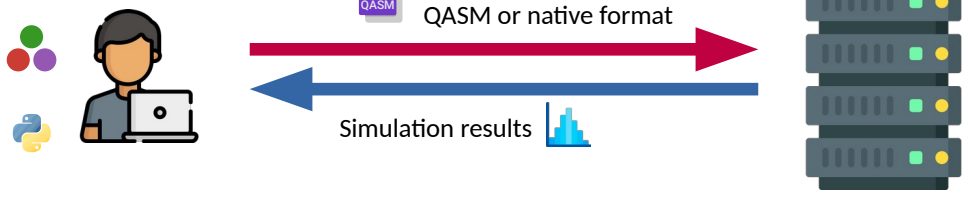
Example from many-body quantum physics:

[**Wellnitz, Pupillo, Schachenmayer, Commun Phys 2022**]

Exact quantum molecular (electro-vibrational) dynamics of 160 coupled molecules

MIMIQ-CIRC Specifications

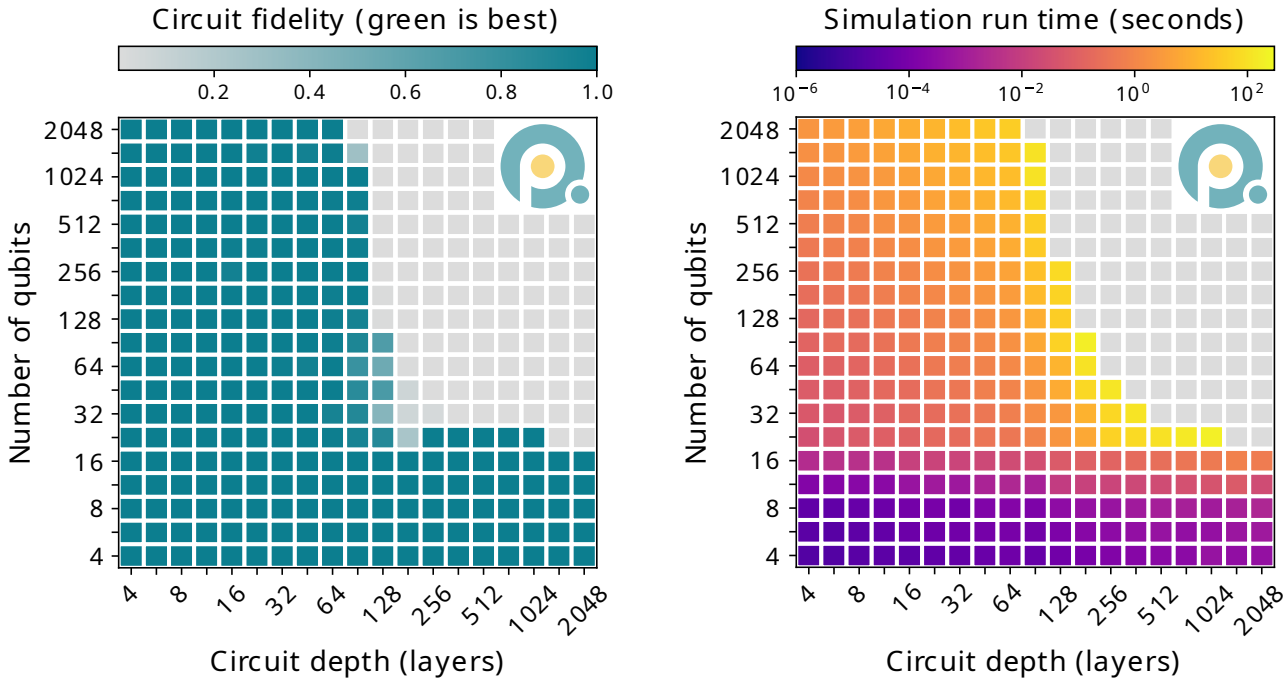
- Fast **statevector** simulator engine.
  Meticulously optimized down to the level of single CPU instructions.
- Large-scale **Matrix Product State** engine (MPS).
  Simulations up to hundreds of qubits, effective gate error below state-of-the-art hardware platforms.
- Automatic **algorithm switching**.
- Intuitive **Python** and **Julia** interfaces.
- Complete **OpenQASM** support.
- SaS solution: Asynchronous workflow



Benchmarks

Dense random Clifford + T benchmark using MIMIQ-CIRC for up to 2048 qubits

Single computational node,
3GHz CPU, 8 cores,
128 GB of RAM



Simulations performed on a single computational node with a maximum run time of 300 seconds per data point.

Optimization & Max-Cut

- Optimization problems in chemistry, finance, logistics and AI.
- Quantum optimizers: **early value** in NISQ era.
  Including VQE, QAOA, and digital adiabatic simulations.

$$U_P(\gamma) = \mathrm{e}^{-\imath\gamma H_P} \qquad H_P = -\sum_{\{u,v\}\in E} Z_u Z_v$$

$$U_M^H(\beta) = \mathrm{e}^{-\imath\beta B} \qquad B = \sum_{j=1}^{n} X_j$$

Encodes the max-cut problem

$$\underbrace{U_P(\gamma_L)U_M(\beta_L)\cdots U_P(\gamma_1)U_M(\beta_1)U_P(\gamma_0)}\,|s\rangle$$

QAOA ansatz

$G = (V, E)$

60 nodes, 131 edges

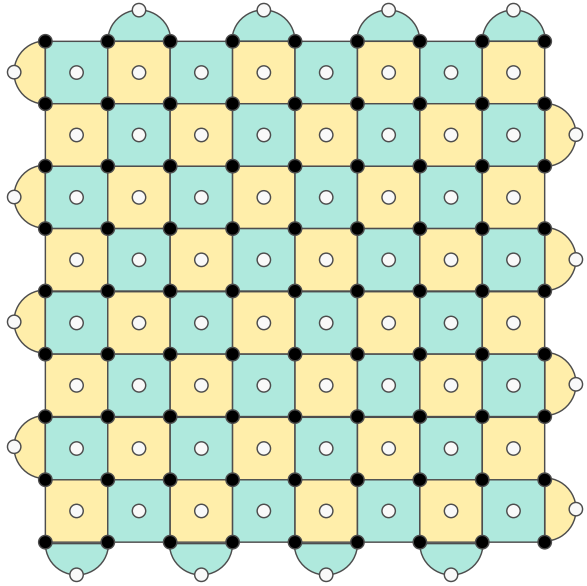
$$\mathrm{p}_{ij} = \frac{1}{|i-j|^{\sqrt{2}}}$$

On MIMIQ-CIRC:
40 repetitions,
unoptimized parameters

Number of gates (multiqubit)	7640 (5240)
Depth	884
Averaged multiqubit gate error	0.00018%
Solution probability	3/250
Execution time	1163s ~ 19 minutes

Quantum Error Correction

- Cutting-edge QEC protocols with **hundreds of qubits**, including:
  - **Non-Clifford operations**
  - Mid-circuit measurements
  - Conditional operations
  - Realistic noise (coming soon)



Example: Surface Code

Distance d = 9
T = 10 cycles

161	qubits
2880	2-qubit gates
881	measurements

~ 20 minutes

Integer Factorization

- Enormous importance for **security** and **cryptography**: basis of widely-used security protocols (RSA)
- **Shor's Algorithm** provides superpolynomial speedup.
  [Shor IEEE Comput. Soc. Press. 1994]
- Benchmarking quantum computers

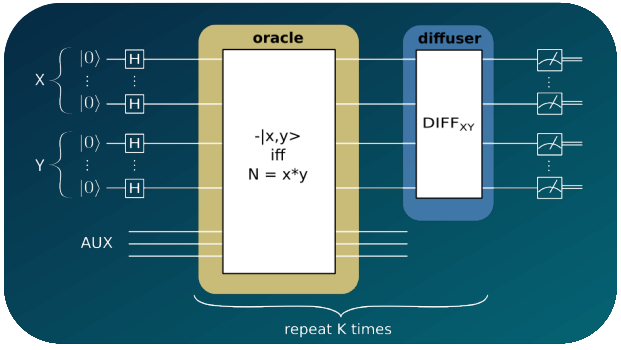
Quantum Best *

21 = 3 × 7

** On quantum computers. General case without oversimplification.*

[Whitlock & Kieu, Quantum Factoring Algorithm using Grover Search, 2023]

- Given an n-bit integer **N** find the prime factors such that **N = p q**
- Factor *n*-bit integers using Grover Search with (2 *n* – 5) qubits



Execution with decomposed operations

	# bits	Time (s)	Trials / Grover steps	Hilbert space size	# multiqubit gates
143 = 13 x 11	8	0.0019	1 / 3	2^{11}	1326
2867 = 61 x 47	12	6.4	1 / 12	2^{19}	26894

With compiled gates:

11212757 = 4999 x 2243

Time: 1.35 seconds

Grover steps: 804

Hilbert space dim: 2^{20}

Advancing MIMIQ-CIRC through HPC

What is in MIMIQ-CIRC future?

- It is not always a matter of speed. Solving large problems require simulating **larger systems** and **higher fidelities**.
- Ongoing exploratory work on heterogeneous and massively parallel computing.
- **Quantum inspired algorithms**:
  MIMIQ provides a **universal interface for MPS**-based solvers and algorithms

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Interested in our journey?

Here’s what you can do next:

- **Investor**:
  Contact us to explore opportunities and delve deeper into the company vision.
- **Product Enthusiasts**:
  Reach out to us to join our pre-release phase for a 15-day free trial.
- **Resource Collaboration**:
  Have resources to share? Let's discuss collaborations.

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Thanks for your attention

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