Università degli Studi di Napoli “Federico II”

Quantum hybrid algorithms for combinatorial optimization problems

Napoli – 19/04/2024

Mara Vizzuso

- **The problem**
- What is QAOA?
- How to improve QAOA?
- Simulations on IBISCO
- Results

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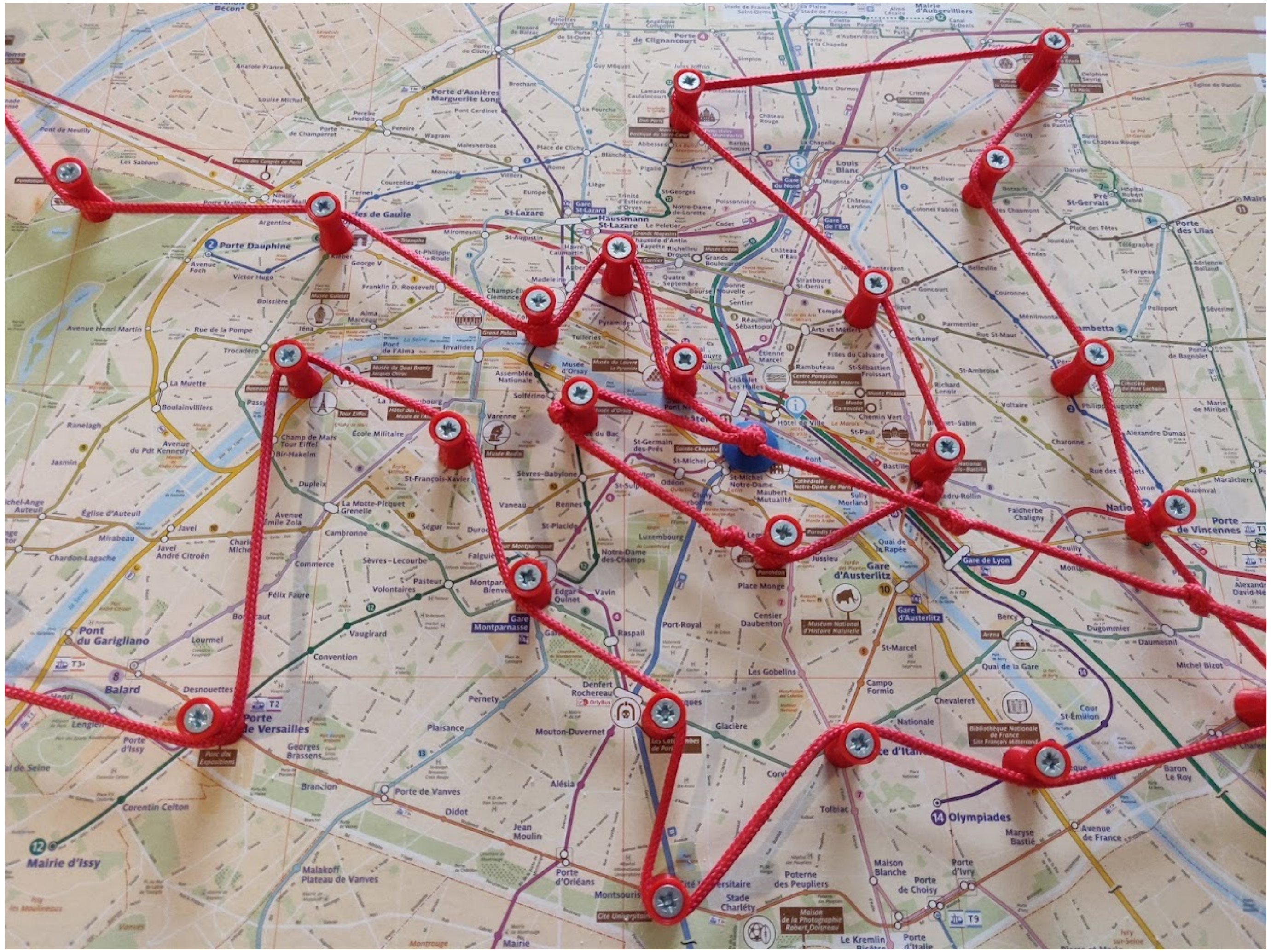
The problem



Travelling salesman problem

↓

Groundstate searching of H_T

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The problem

Example:

Naples traffic

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The problem

$$H_T = \sum_{uv \in E} W_{uv} \sum_{j=1}^{N} x_{u,j} x_{v,j+1}$$

(Travelling Salesman)

Tricarico (MT)

$$H_0 = \sum_{i=0}^{N} \sigma_i^X$$

(Easy to solve)

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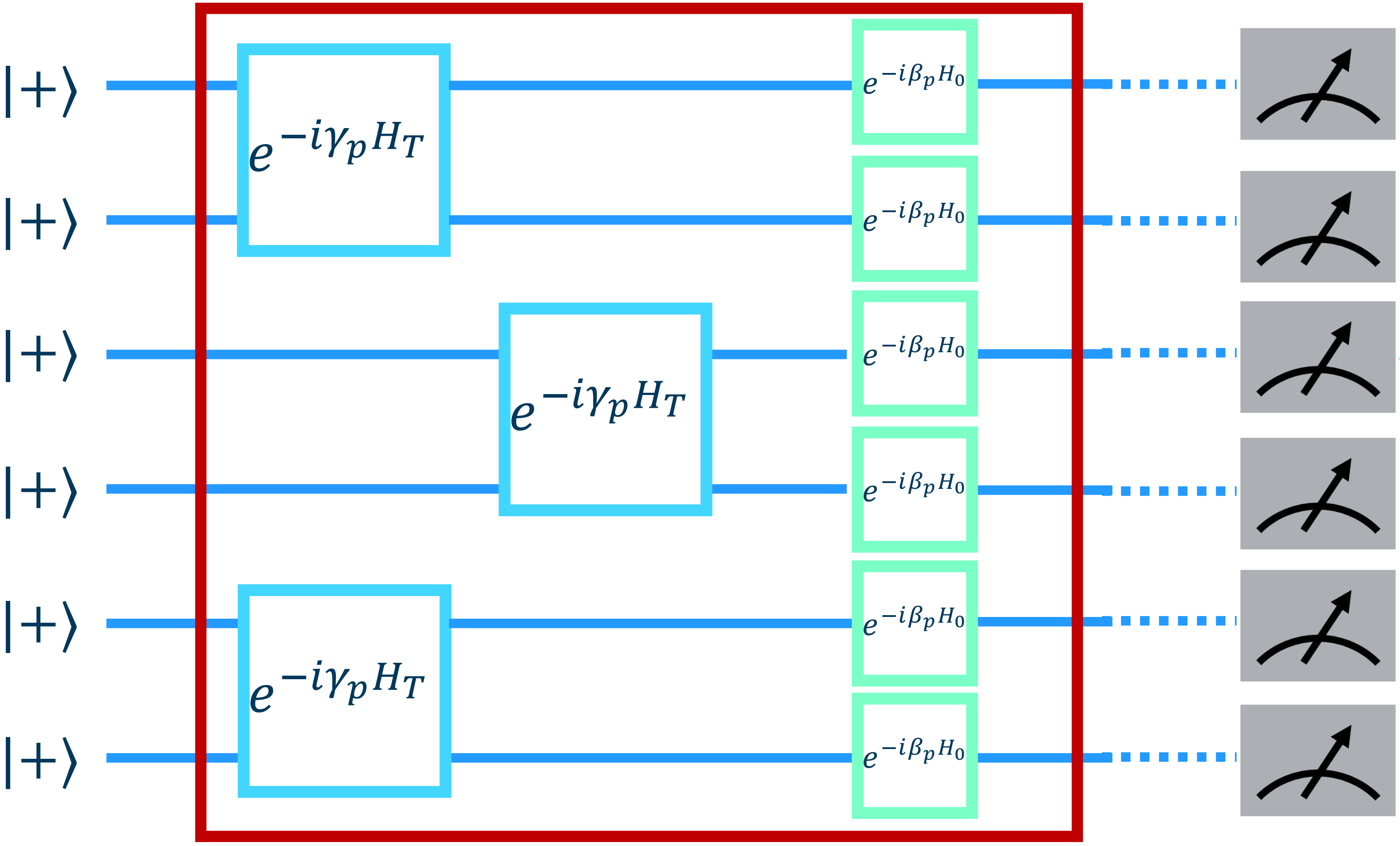
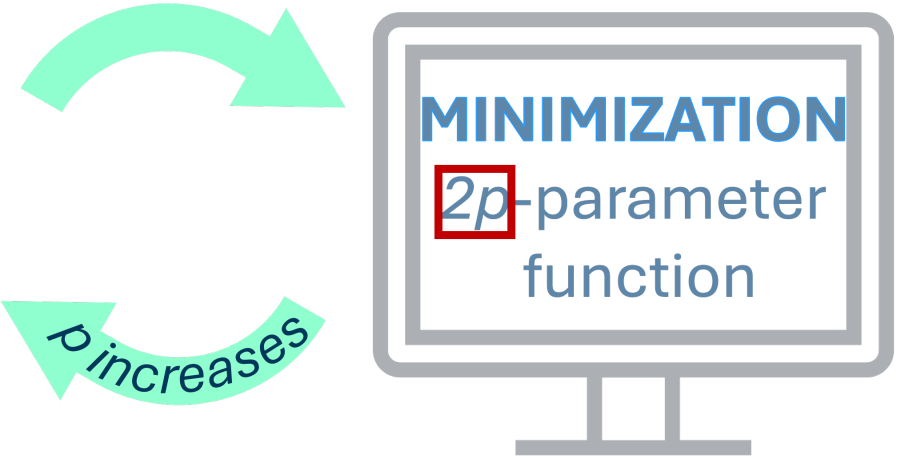
$\vec{\lambda} = \lambda_1, \dots, \lambda_{p_{fin}}$

What is QAOA?



p −th QAOA step



$$f(\vec{\gamma}, \vec{\beta}) = \langle \psi_0 \square | H_T | \square \psi_0 \rangle$$

QAOA unitary operations

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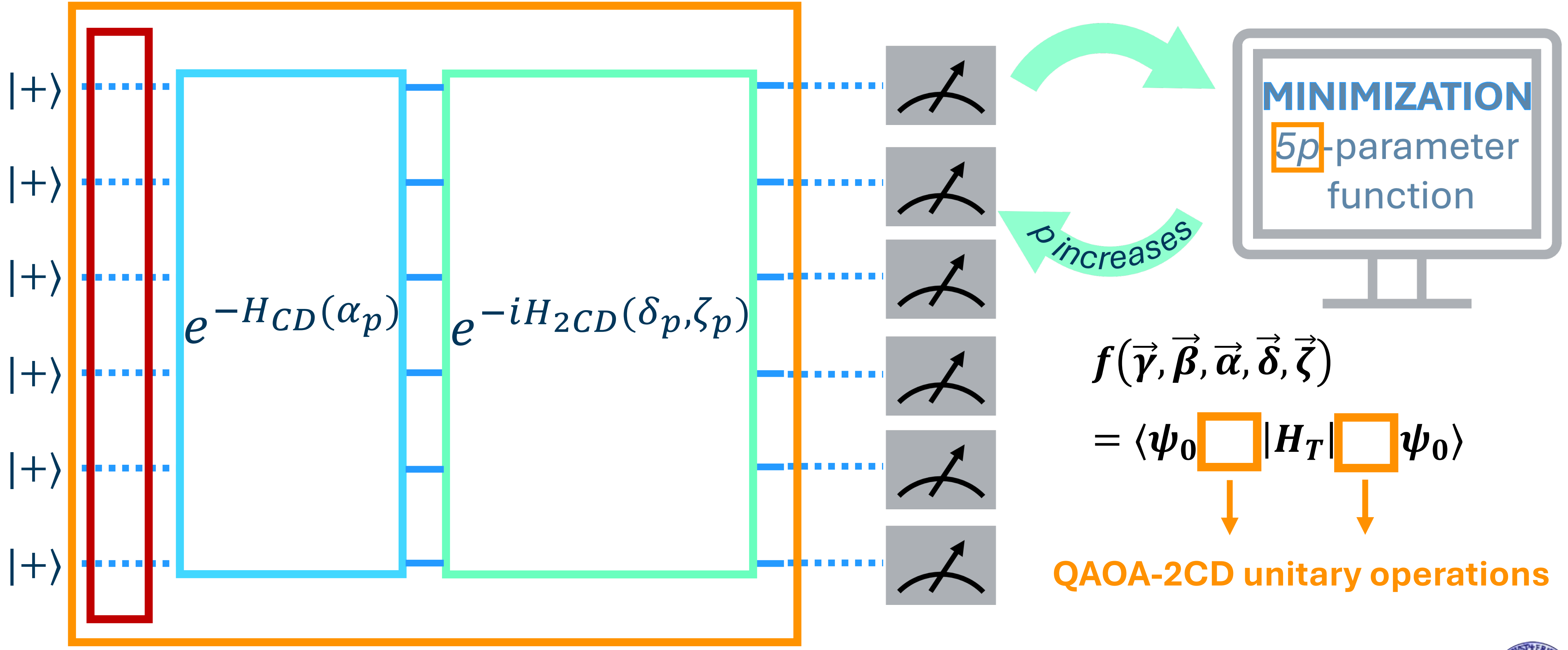
$\vec{\lambda} = \lambda_1, \dots, \lambda_{p_{fin}}$

How we improve QAOA?



$$f(\vec{\gamma}, \vec{\beta}, \vec{\alpha}, \vec{\delta}, \vec{\zeta}) = \langle \psi_0 \square | H_T | \square \psi_0 \rangle$$

QAOA-2CD unitary operations

p –th QAOA step

p –th QAOA-2CD step

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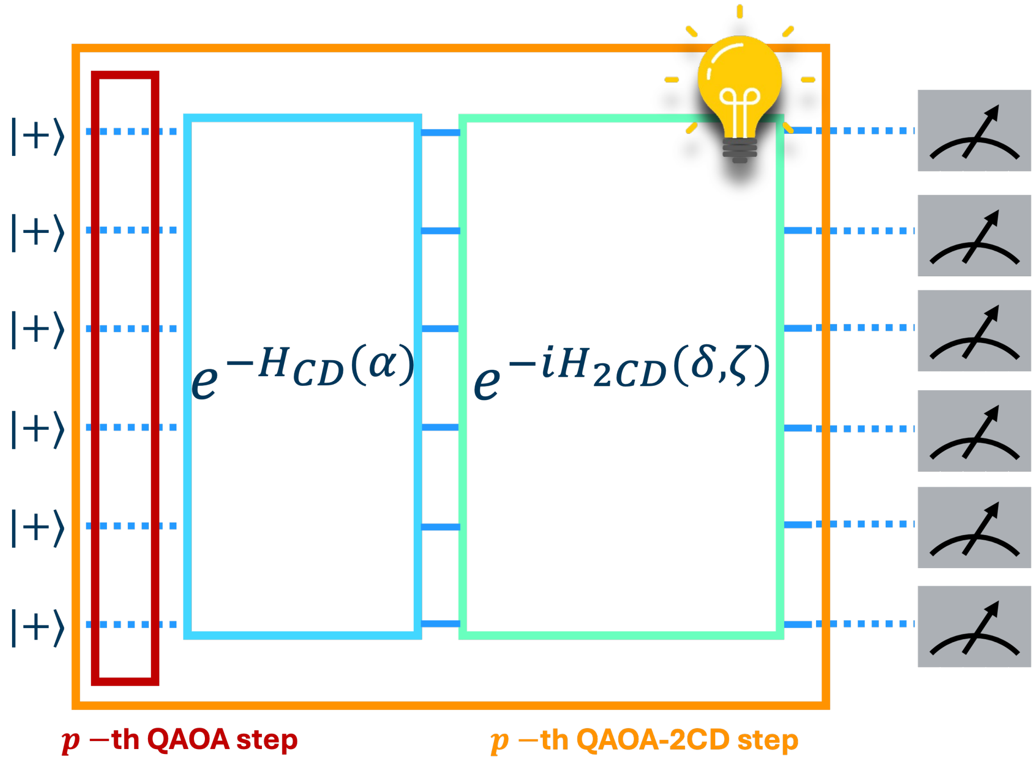
How we improve QAOA?

$$H_{CD}(\alpha) = \alpha[H_0, H_T]$$

$$\boldsymbol{H_{2C}(\delta,\zeta) = \delta[H_0,[H_0,H_T]] - \zeta[H_T,[H_0,H_T]]}$$

Second order of BHC formula



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Simulation on IBISCO

Simulation of quantum computer

Initial state: diagonalization of matrices
$\dim(\mathcal{H}) = 2^N = 2^{10},\ 2^{16},\ 2^{20}$

Quantum Gates: use of of matrices
$\dim(\mathcal{H}) = 2^N = 2^{10},\ 2^{16},\ 2^{20}$

- exponential operation
- computation of commutator

Target state (comparing algorithm results): diagonalization of matrices
$\dim(\mathcal{H}) = 2^N = 2^{10},\ 2^{16},\ 2^{20}$

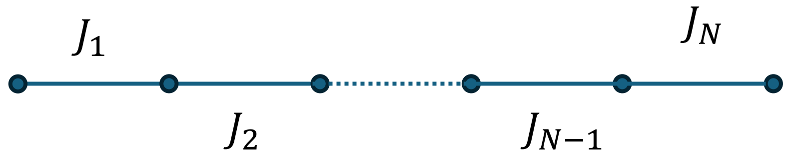
Classical minimization

Use of *optimparallel*

Number of parameter: $N_p = 2p, 3p, 5p$
for $p = 1 \ldots 20$

For each minimization $s = 20$
independent runs

Simulation on IBISCO



All these operations for $n = 60$ instances (different J_k)!

Total number of matrices calculated: $\mathrm{N_M} = 900$

Maximum dimension : $\sim 10^5 \mathrm{x} 10^5$ (calculated 300 times)

Total number of operations: $\sim 2 \cdot 10^5$

Time on IBISCO : **one week**

Time on common pc: **very huge**

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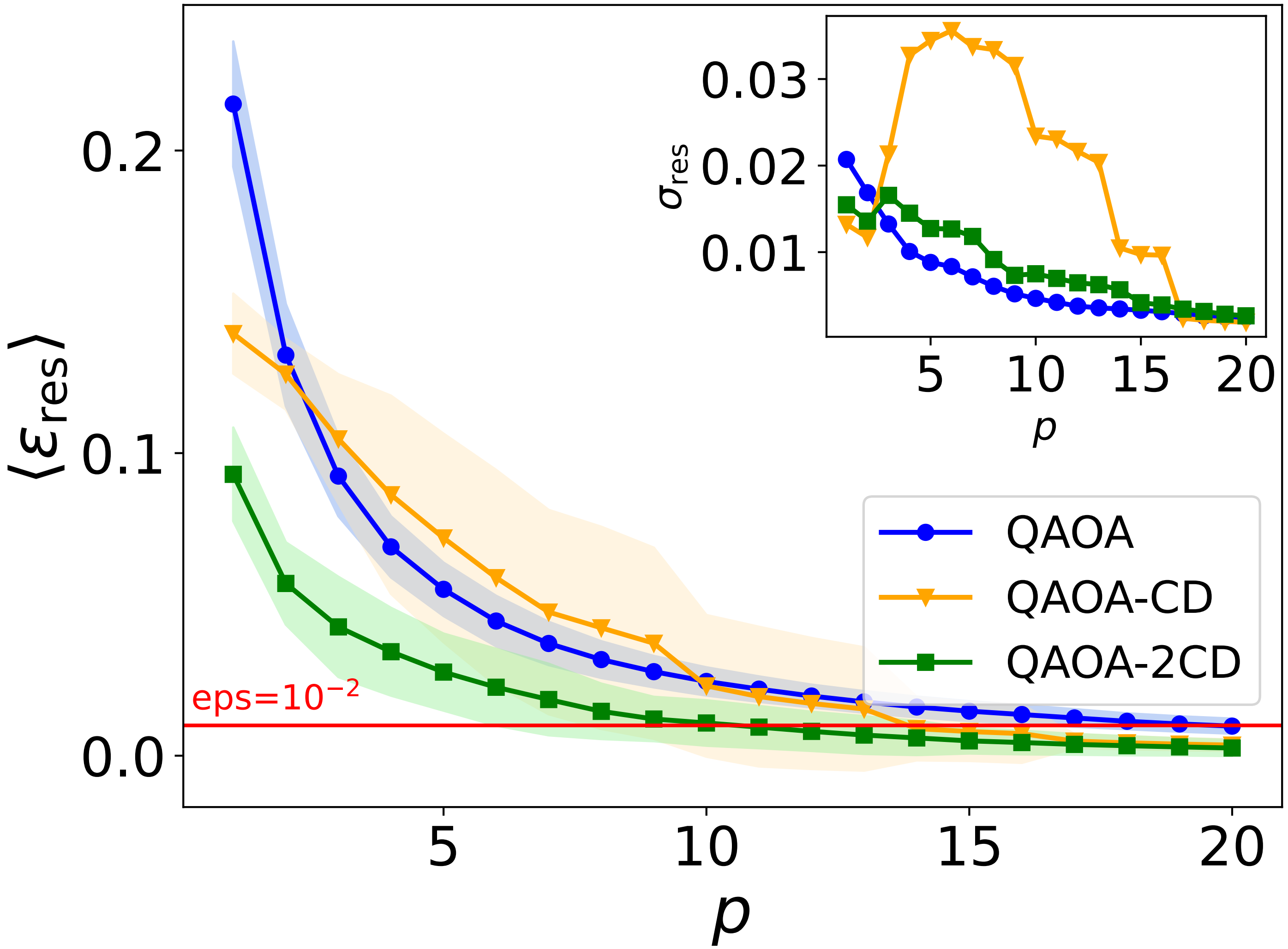
Results



Better performances than QAOA and QAOA-CD

Shorter convergence times

Best approximation

Vizzuso, Mara, et al. "Convergence of digitized-counterdiabatic QAOA: circuit depth versus free parameters." *New Journal of Physics* 26.1 (2024): 013002.

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Conclusions

- Better approximation than the algorithms used to date
- Large number of parameters can be controlled with classical techniques

Future perspectives:

- Implementation on long range-models
- Studying phase transitions
- Implementation on gpu and better parallelization

THANKS FOR THE ATTENTION

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