



Projecting NISQ-era quantum advantage with QAOA

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[Guerreschi & Matsuura, *Scientific Reports*, 9, 6903 (2019)]

[Larkin, Justice & Guerreschi, arXiv:2005.XXXX] <in preparation>

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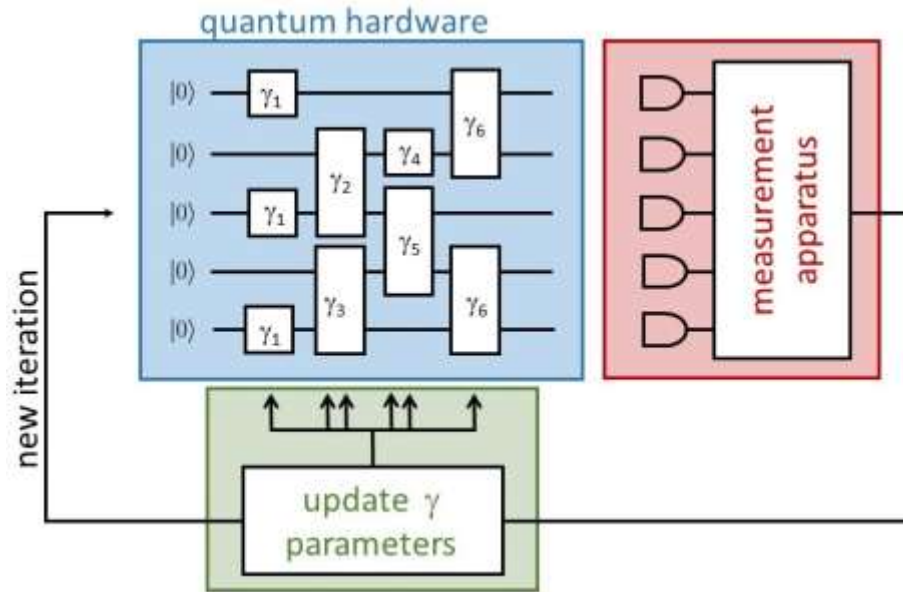
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Variational quantum algorithms

- minimization problems
- approximate solution



Variational quantum algorithms

Variational Quantum Algorithms (VQAs) are ideally suitable for short-term applications:

- hybrid quantum-classical algorithms: part of the **computational cost is offloaded** to classical processors
- circuits are **relatively shallow**: without expensive subroutines like quantum phase estimation
- robust to systematic noise: from the **optimization** of the circuit's parameters
- address very **important problems**: energy of molecular systems (VQE), binary optimization (QAOA), ...

Variational quantum algorithms

Variational Quantum Algorithms (VQAs) are ideally suitable for short-term applications:

-
- Quantum supremacy have been claimed last autumn.
Are we ready for applications?
- Today? Tomorrow?
-

Variational quantum algorithms

Hardware has limited connectivity.
Extra operations required for routing.

Execution time includes quantum circuit
and classical optimization, but also
communication latency.

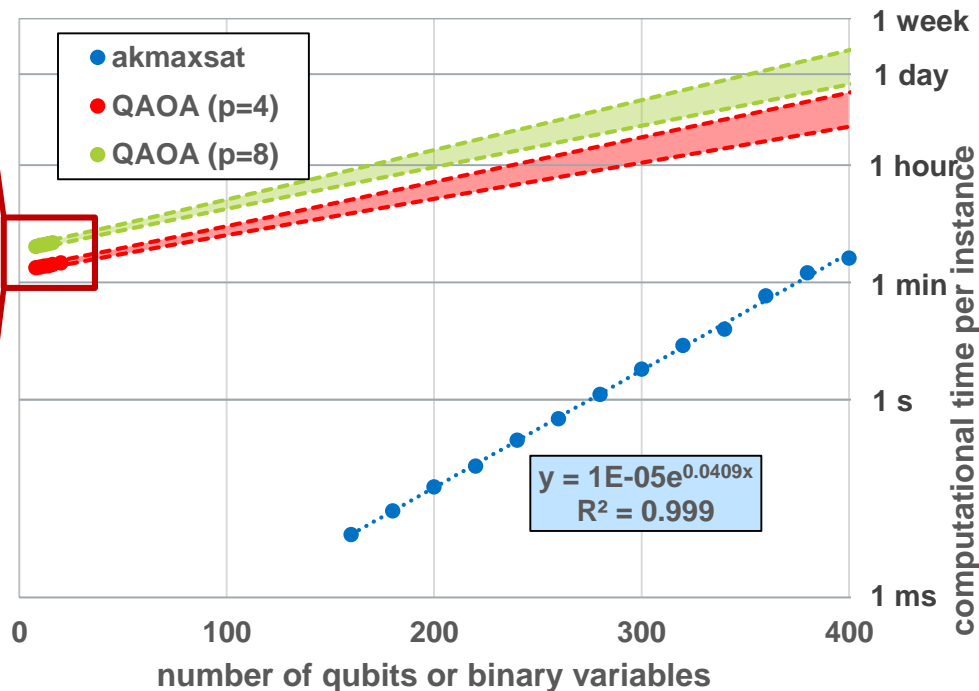
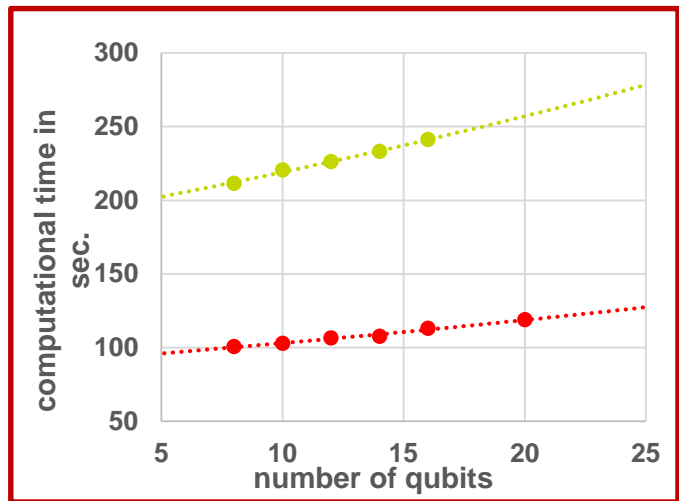
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Fierce competition from
classical alternatives

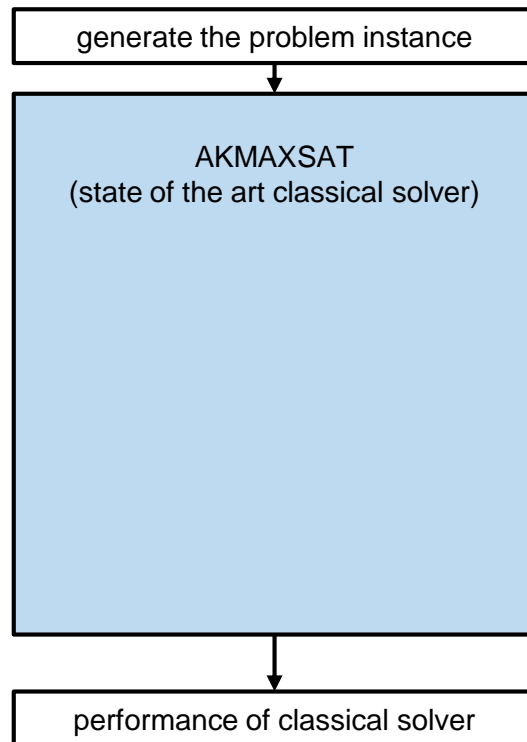
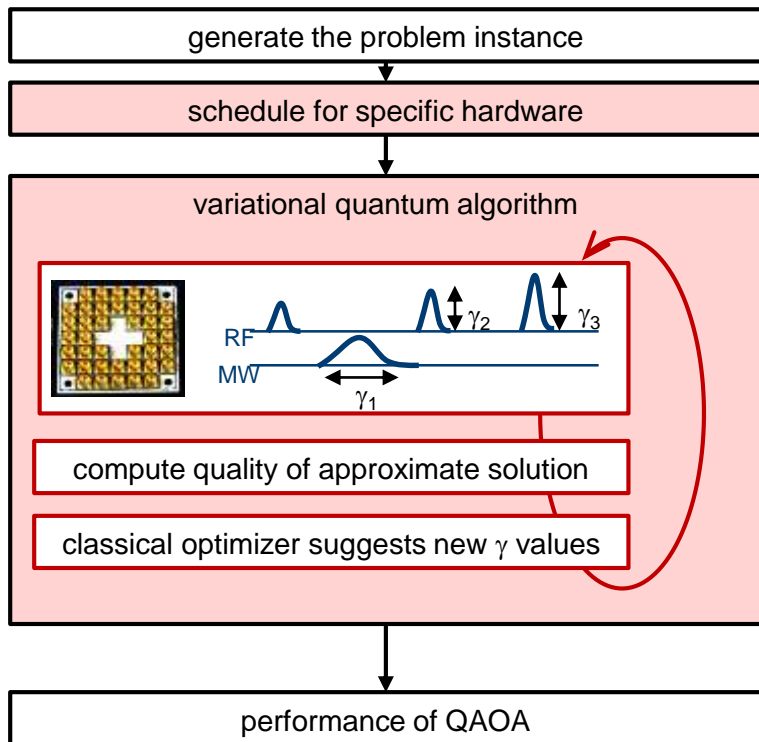
100s or 1000s of different
parameter choices

Benchmarking QAOA for Max-Cut on 3-regular graphs



- Limited connectivity
- Noise and decoherence
- Multiple local searches

Last year's approach



Last year's approach... and its extension

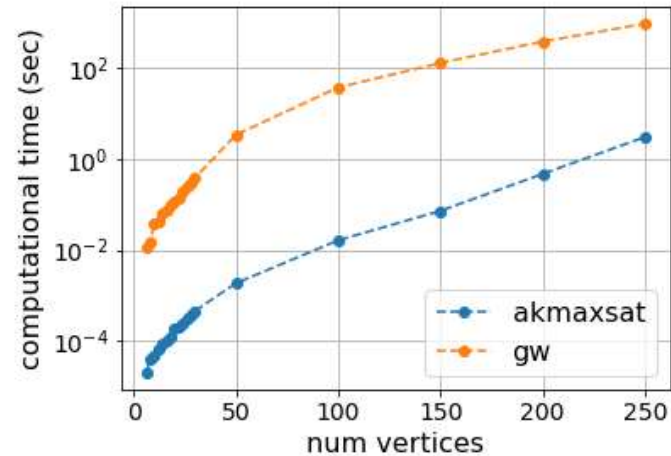
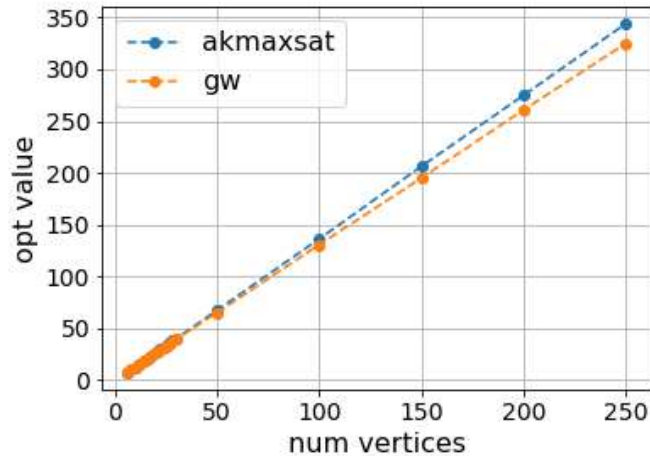
We learned that QAOA must improve by orders of magnitude!

- Quantum hardware: more qubits, high-fidelity gates, 2D connectivity, parallel operations
[Kandala et al., *Nature*, 567, 491-495 (2019)] [Arute et al., *Nature*, 574, 505-510 (2019)]
- Software tools: compilers and mappers
[Lao et al., arXiv:1908.04226] [Guerreschi, arXiv:1912.00035]
- **Parameter optimization:** less iterations, using gradients, different figure of merit guiding optimization, ...
[Guerreschi & Smelyanskiy, arXiv:1701.01450] [Barkoutsos et al., arXiv:1907.04769]
- Initial guess of parameters' values: correlated with problem instances in same class
[Wecker et al., *Physical Review A*, 94, 022309 (2016)] [Brandão et al., arXiv:1812.04170]
- **Problem selection:** look for classical hard instances
[Moussa, Calandra, & Dunjko, arXiv:2001.08271]
- But also... use **classical approximate solvers** to compare against
[Goemans & Williamson, *Journal Of The ACM*, 42(6), 1115-1145 (1995)]

Classical (approximate) solvers: akmaxsat, GW, ...

Random 3-regular graphs, averaged over 20 instances:

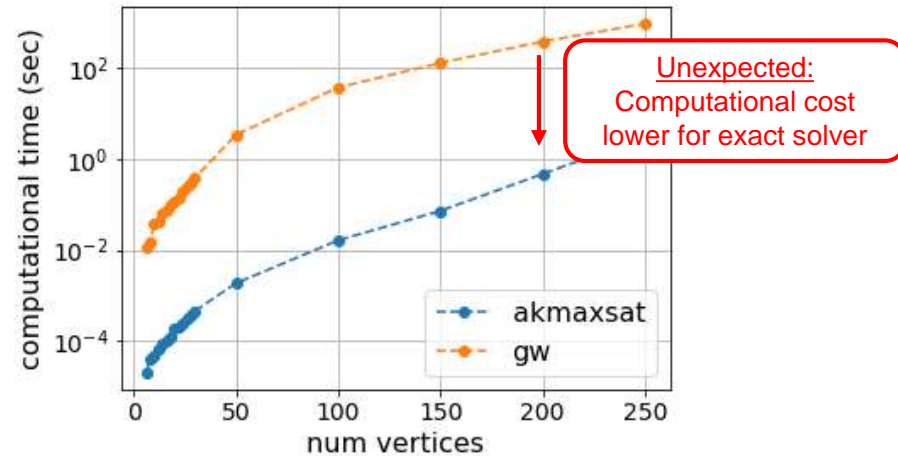
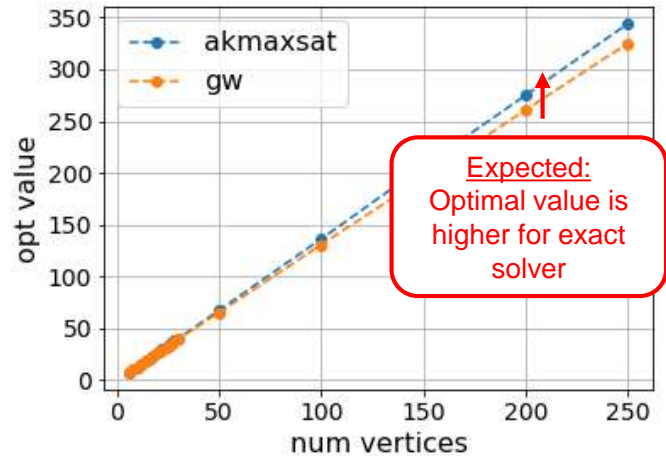
- **akmaxsat** → exact solver for SAT
- **Goemans-Williamson** → heuristic alg. for MaxCut



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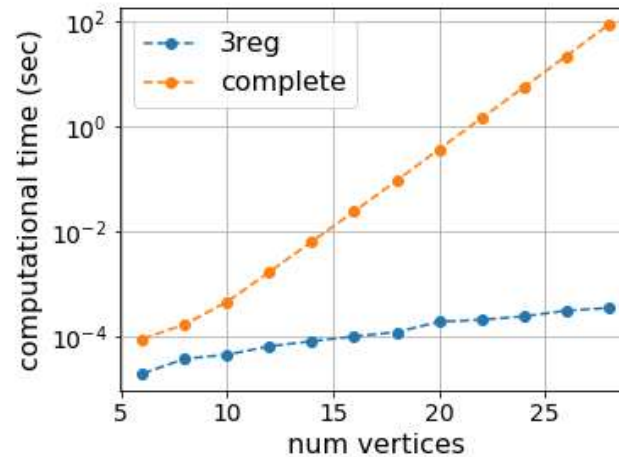
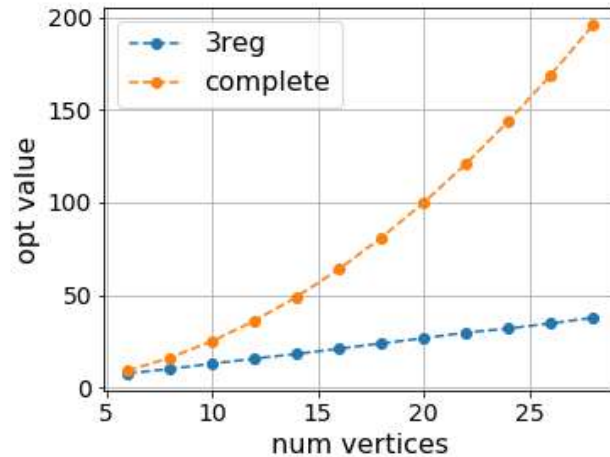
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Problem selection: k-regular, complete, Ergdos, ...

akmaxsat:

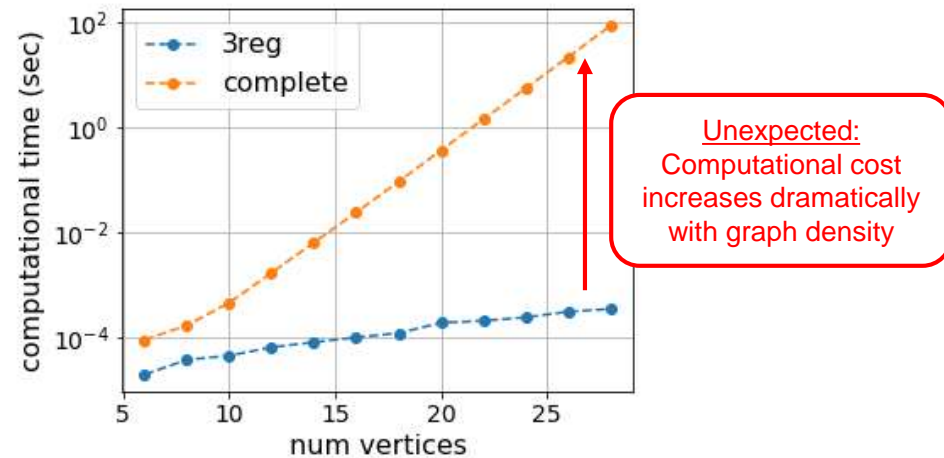
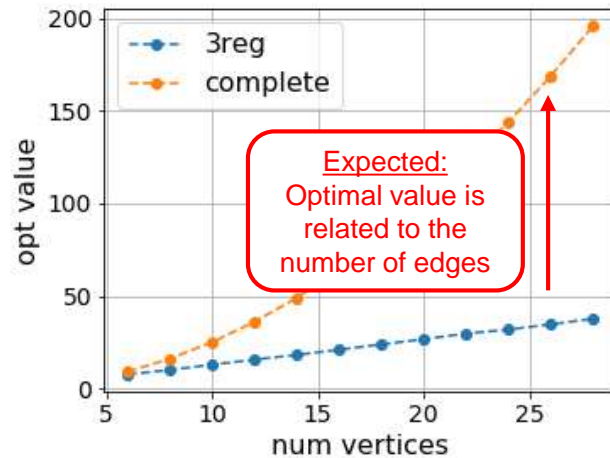
- 3-regular graphs \rightarrow num edges = $3n/2$
- complete graphs \rightarrow num edges = $n(n-1)/2$



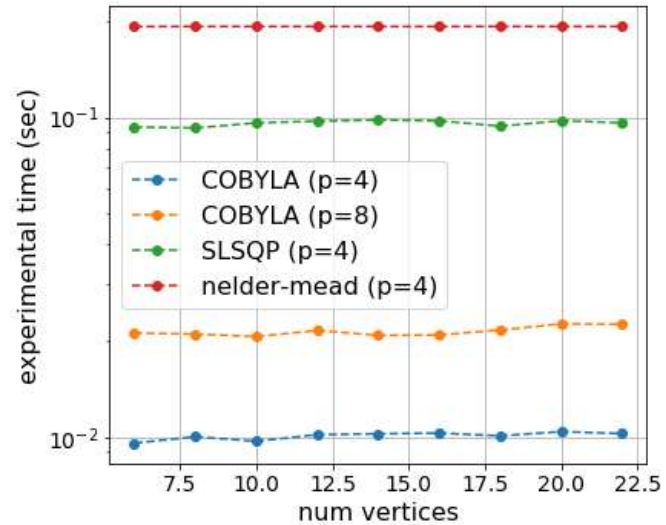
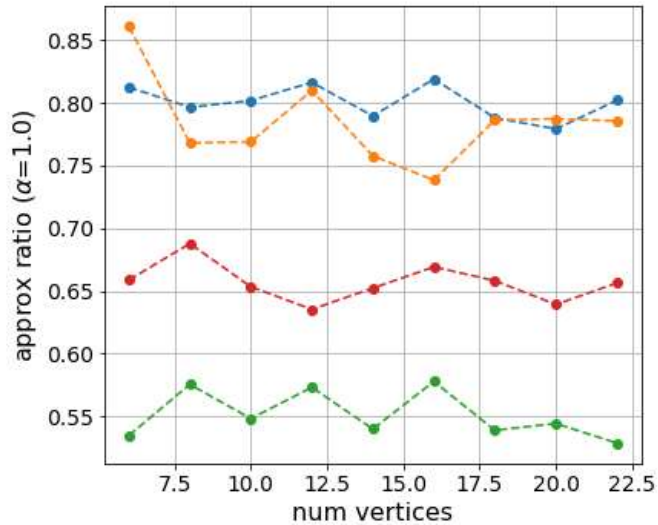
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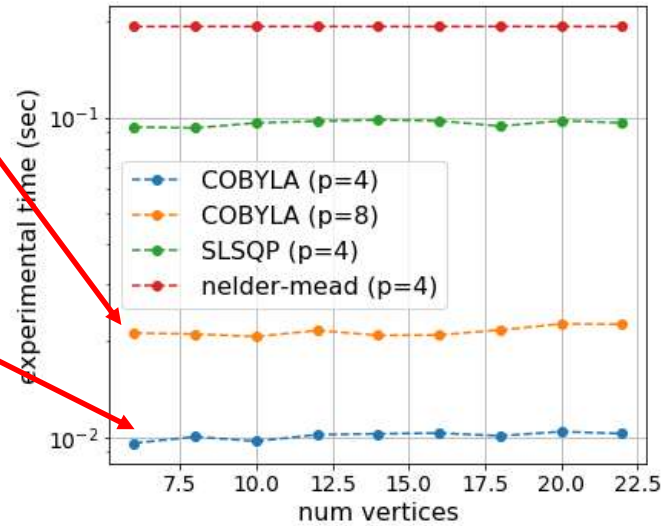
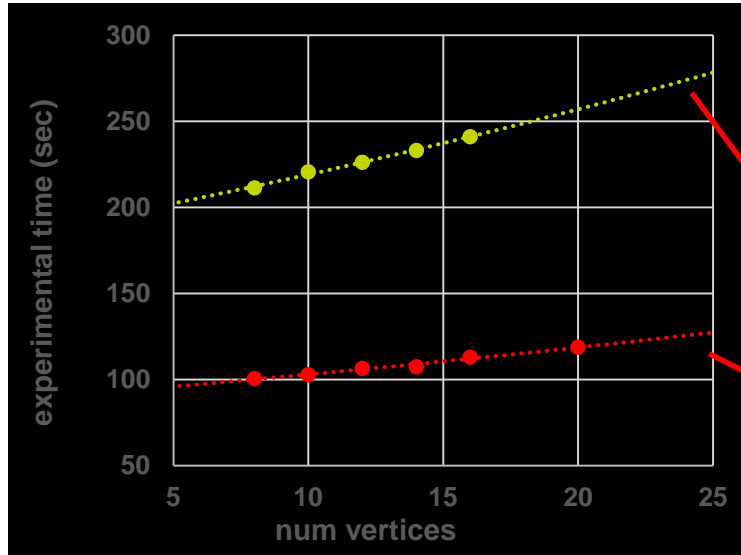


Parameter optimization: COBYLA, SLSPQ, NM, ...



Experimental time reduced by 4 orders of magnitude

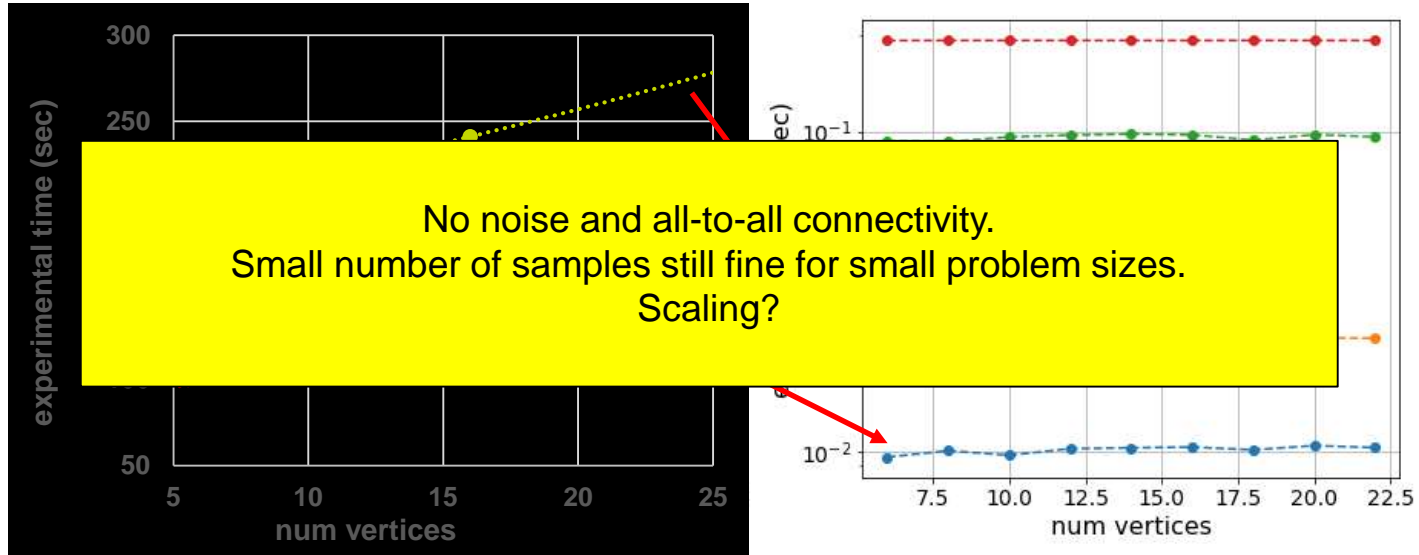
Nelder-Mead with 10,000 samples per function evaluation



COBYLA with 100 samples per function evaluation

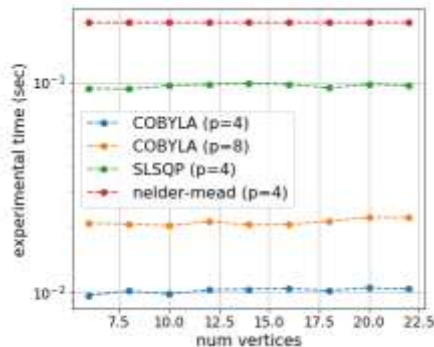
Experimental time reduced by 4 orders of magnitude

Nelder-Mead with 10,000 samples per function evaluation





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[Guerreschi & Matsuura, *Scientific Reports*, 9, 6903 (2019)]

[Larkin, Justice & Guerreschi, arXiv:2005.XXXX] <in preparation>

Project NISQ-era advantage:

1. compared to (approximate) solvers
2. focusing on classically hard instances
3. with most suitable classical optimizers and protocols

Together with: Anne Matsuura (Intel)
Jongsoo Park (Intel → FB)
Mikhail Smelyanskiy (Intel → FB)

Thanks for the attention!