Quantum algorithms & applications

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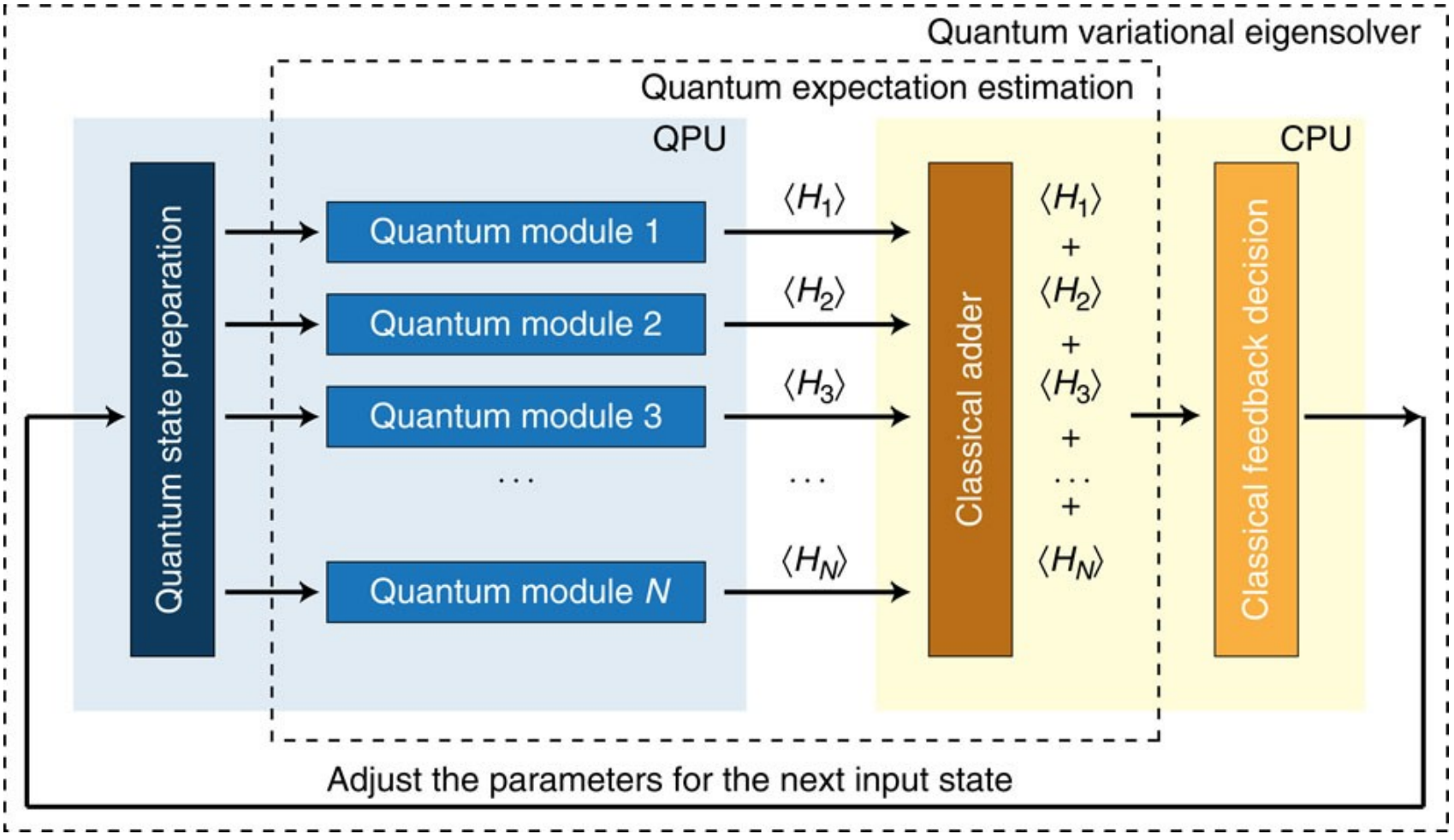
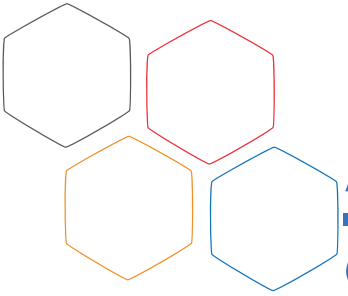
Quick history of quantum algorithms

1992	Deutsch-Jozsa algorithm
1994	Shor's algorithm
1996	Grover's algorithm
2009	HHL algorithm[a]
2014	Variational Quantum Eigensolver (VQE)
...	`https://quantumalgorithmzoo.org/`

[a] Aaronson, "Read the fine print".

Variational Quantum Eigensolver





Algorithm development

Quantum wave equation solver

Driving idea: can we solve PDE with quantum computers?

1. HHL[1] with well-known classical discretisation methods?
2. Direct resolution of the wave equation[2]

Work performed

Implementation of a quantum program that solves the wave equation[3].

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[1] Harrow, Hassidim, and Lloyd, "Quantum Algorithm for Linear Systems of Equations".

[2] Costa, Jordan, and Ostrander, "Quantum algorithm for simulating the wave equation".

[3] Suau, Staffelbach, and Calandra, "Practical Quantum Computing: Solving the Wave Equation Using a Quantum Approach".

QatHS results

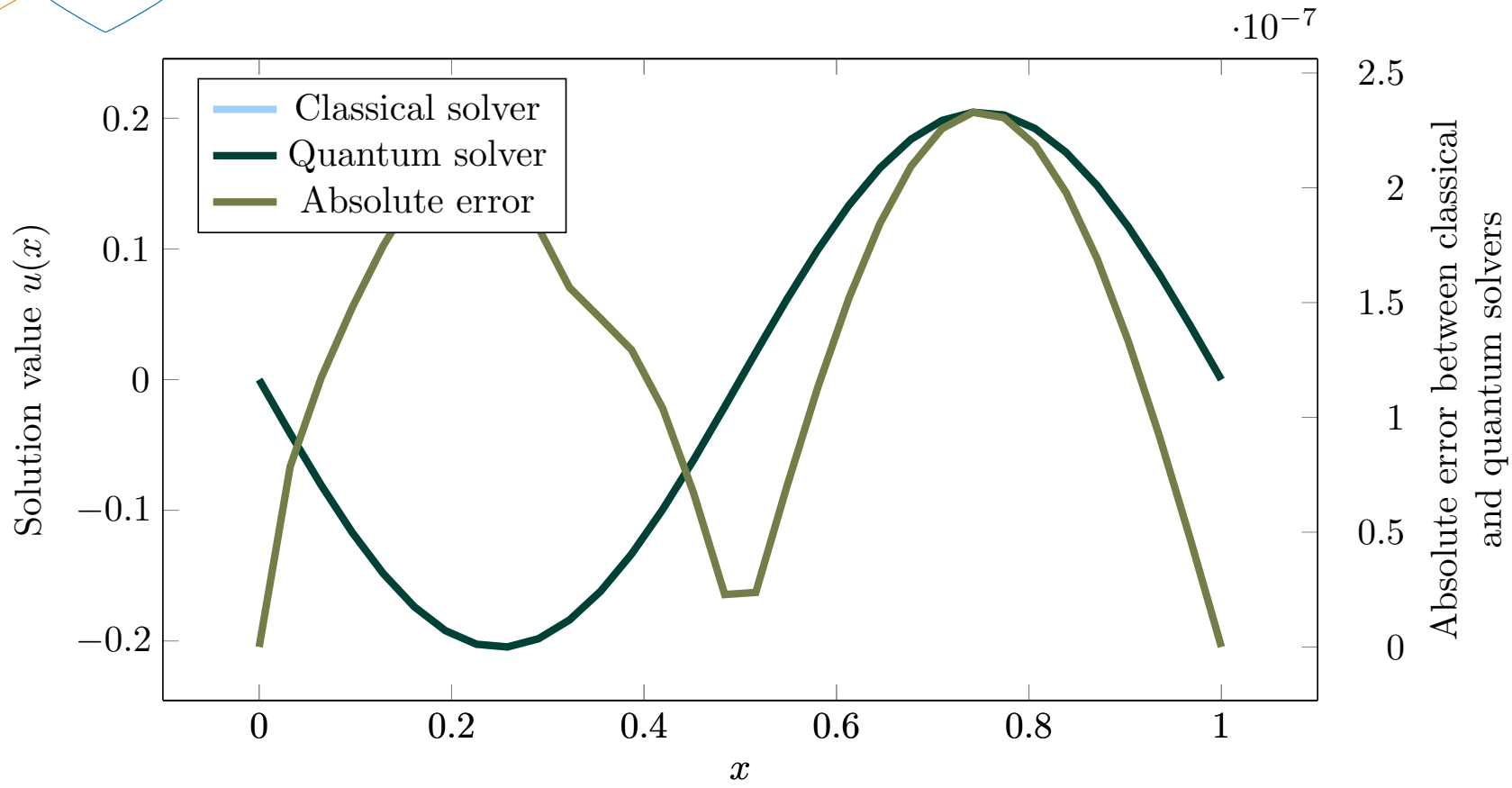
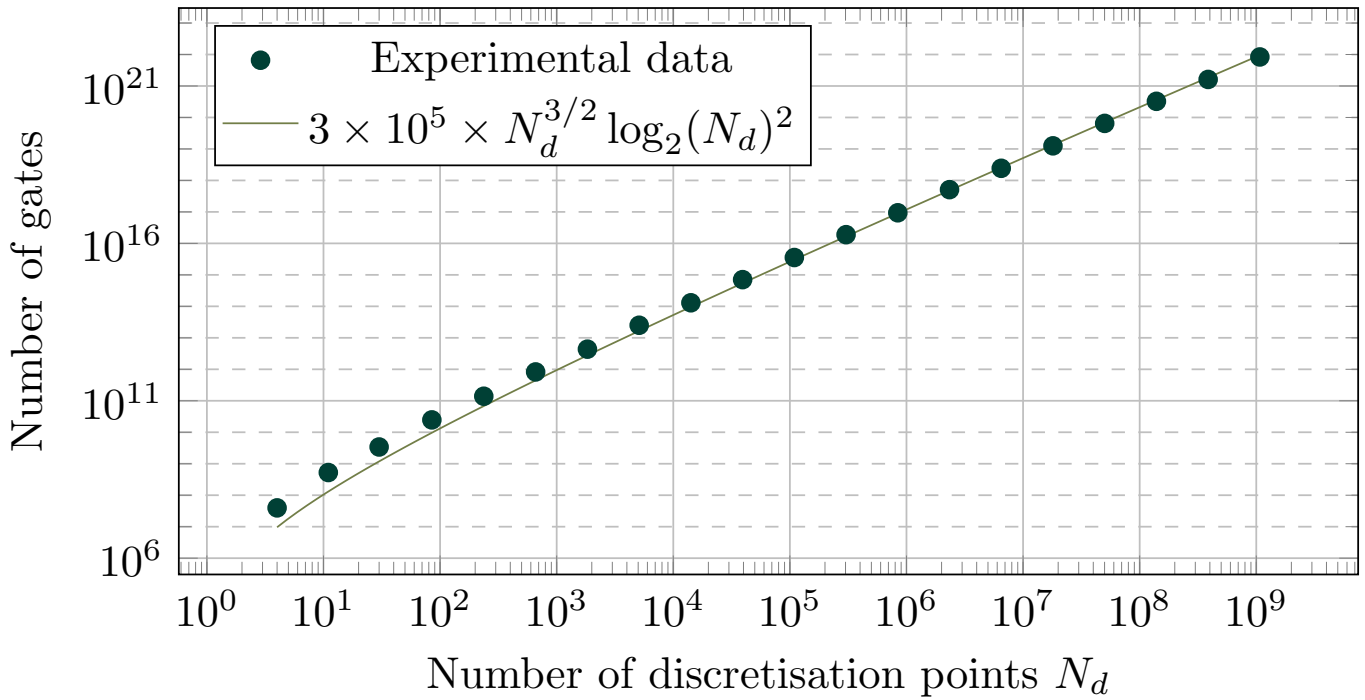
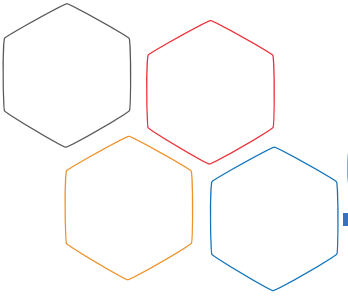


Figure: Plot of the solution obtained with the quantum solver implementation and with the classical finite-difference solver. Absolute error between the results obtained by the two implementations is of the order of 10^{-7}.

QatHS results

Number of quantum gates needed to execute the wave equation solver w.r.t the number of discretisation points used





QatHS resource estimation and conclusion

The quantum wave equation solver works as expected:

- Sufficient precision
- Non-published work on non-constant propagation speed c

But is not efficient enough

- Too much quantum gates
- No quantum advantage

Variational Quantum Linear Solver (VQLS)

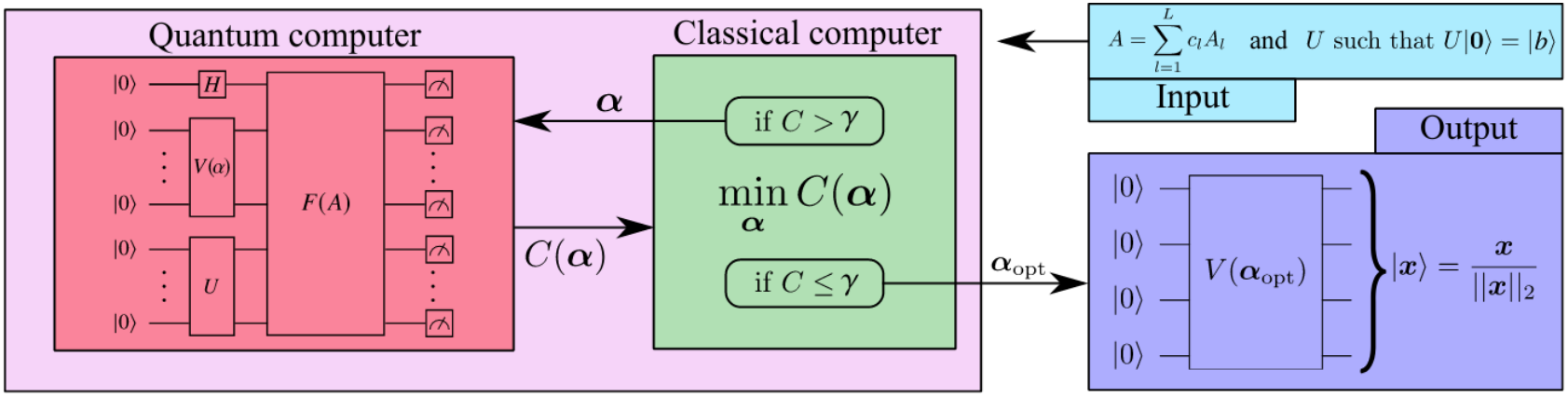
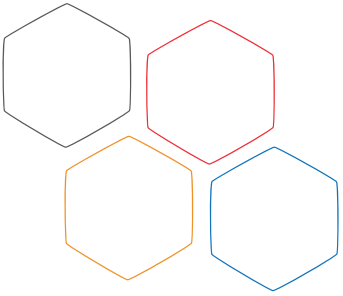


Figure: Illustration of the VQLS algorithm from[4]

[4] Bravo-Prieto et al., "Variational Quantum Linear Solver".



Variational Quantum Linear Solver (VQLS)

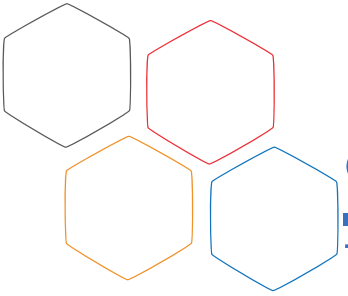
Preliminary results

Works as expected on simulator

- converges to solution
- acceptable precision
- is able to solve multiple different linear systems

Experiencing issues on real hardware

- convergence is harder to obtain
- quantum errors seem to have a non-negligible impact on the optimisation process
- gradient-based optimisation is not efficient in practice



qprof

The **q**uantum **prof**iler

Problem:

No tool to analyse quantum programs efficiency. Optimisation is:

- automatically applied by compiler
- hand-made with intuition, theory and tedious code exploration

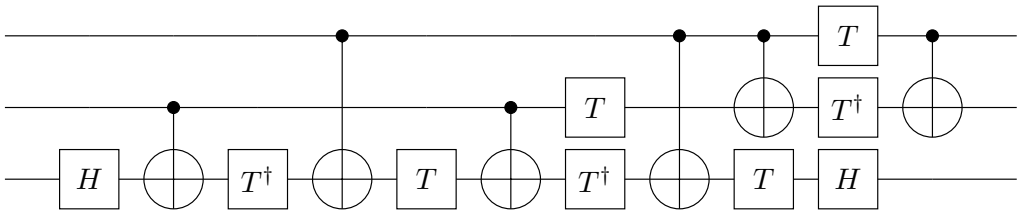
Proposed solution:

Create a tool to help programmers understanding their implementation

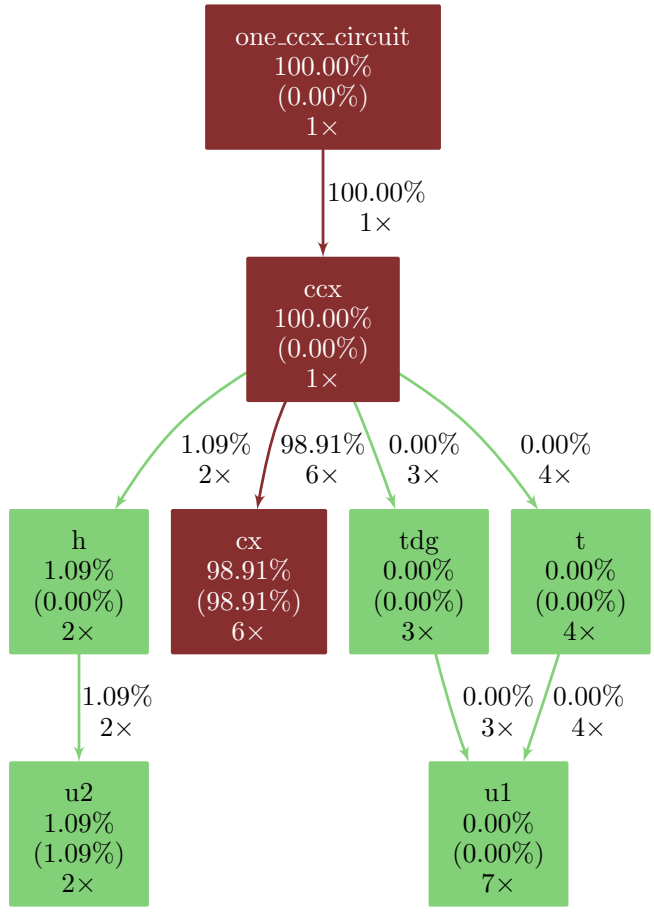
- inspired from classical profiling tools
- re-using well-known output formats

qprof

Example of output



(a) Implementation of the Toffoli gate



(b) Call-graph of a toffoli gate implementation

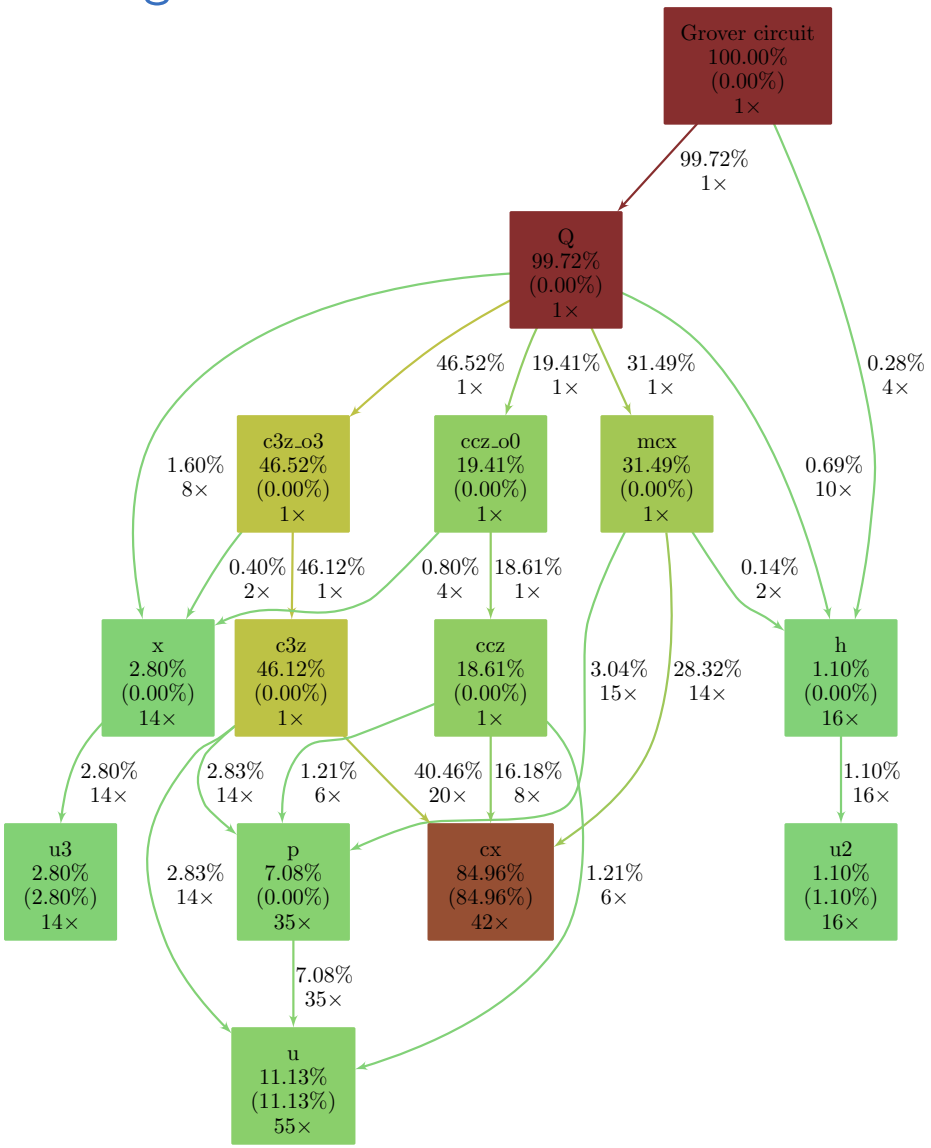
qprof

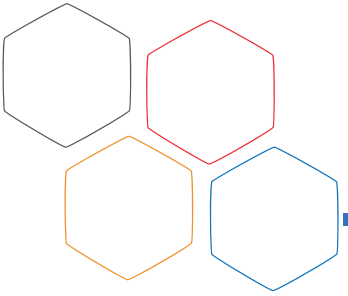
Example of output – Grover's algorithm

Grover's algorithm

Thanks to qprof, the representation is:

- easy to read
- synthetic
- easy to understand





Conclusion

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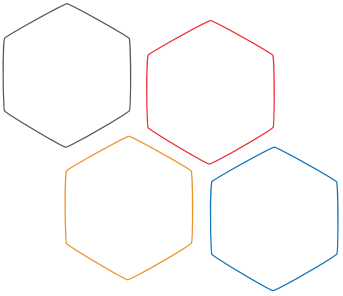
- Both **software** and **hardware** have a long way to go
- Development environments are improving at a fast pace
- Hardware have seen groundbraking announcements in the last few months...
- ...but is still not performant enough to see any advantage



Questions?

Any Question?

Slides and links to papers available at:

https://adrien.suau.me/talk/quantum-algorithms-applications/