UNIVERSITATEA LUCIAN BLAGA DIN SIBIU
HPI Hasso Plattner Institut Digital Engineering · Universität Potsdam
CLUJ IT
Sibiu IT Cluster
SID 2025
Sibiu Innovation Days
06-07 November, Sibiu - RO
EMERGING DISRUPTIVE TECHNOLOGIES:
Balancing Innovation, Risks, and Societal Impact

Hybrid benchmarking of quantum algorithms

Andreea Lefterovici

What is quantum computing?

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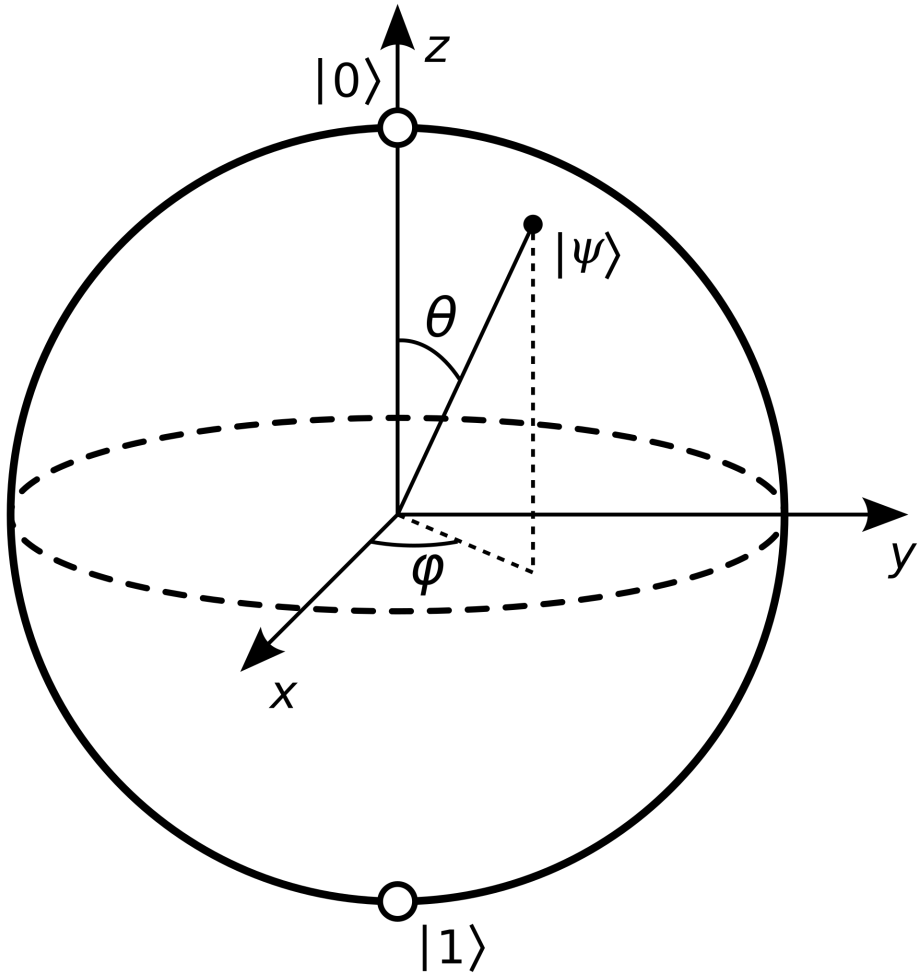
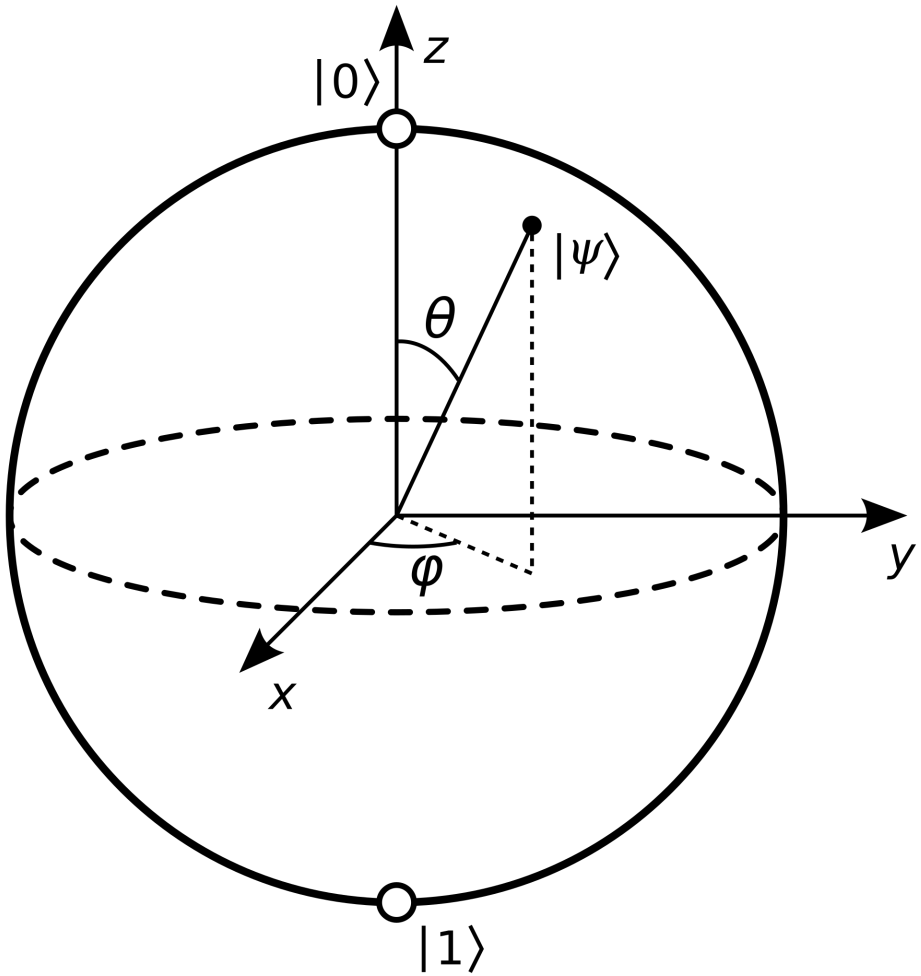
- Classical computers use bits: 0 or 1
- Quantum computers use qubits: 0, 1 or a linear combination of 0 and 1

The quantum bit (qubit)



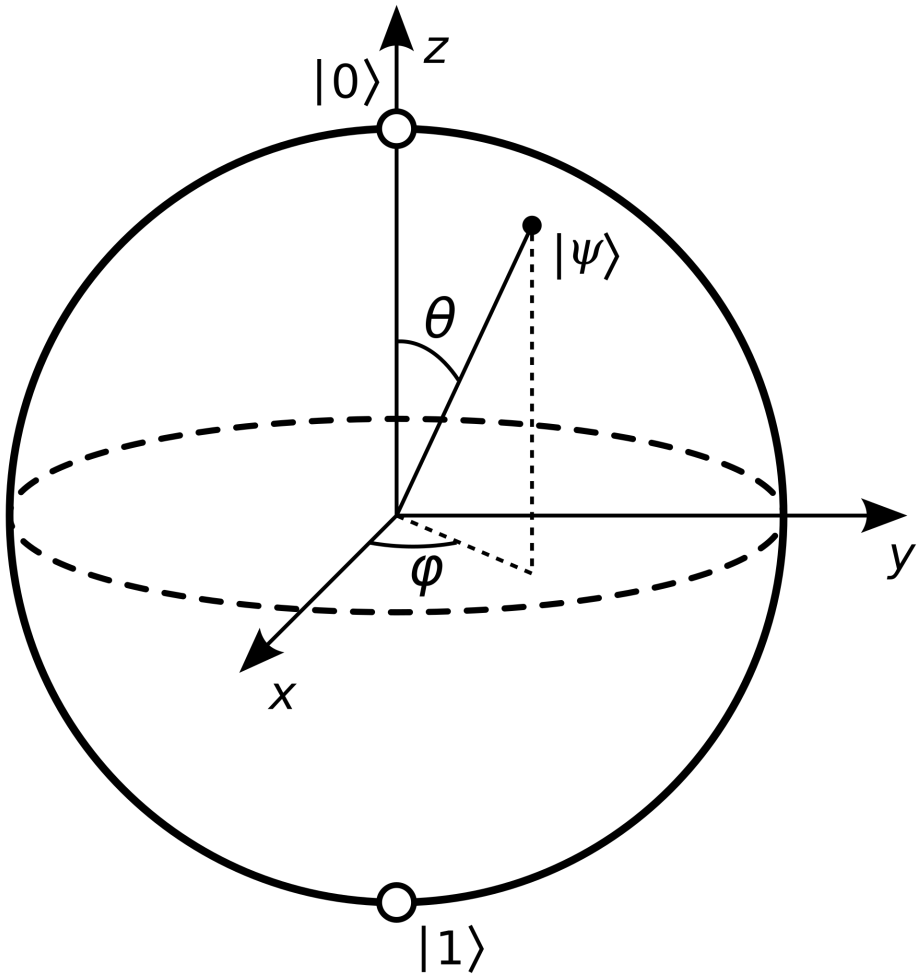
The quantum bit (qubit)



$|\psi\rangle=\alpha|0\rangle+\beta|1\rangle$

where
$|\alpha|^2+|\beta|^2=1$

The quantum bit (qubit)



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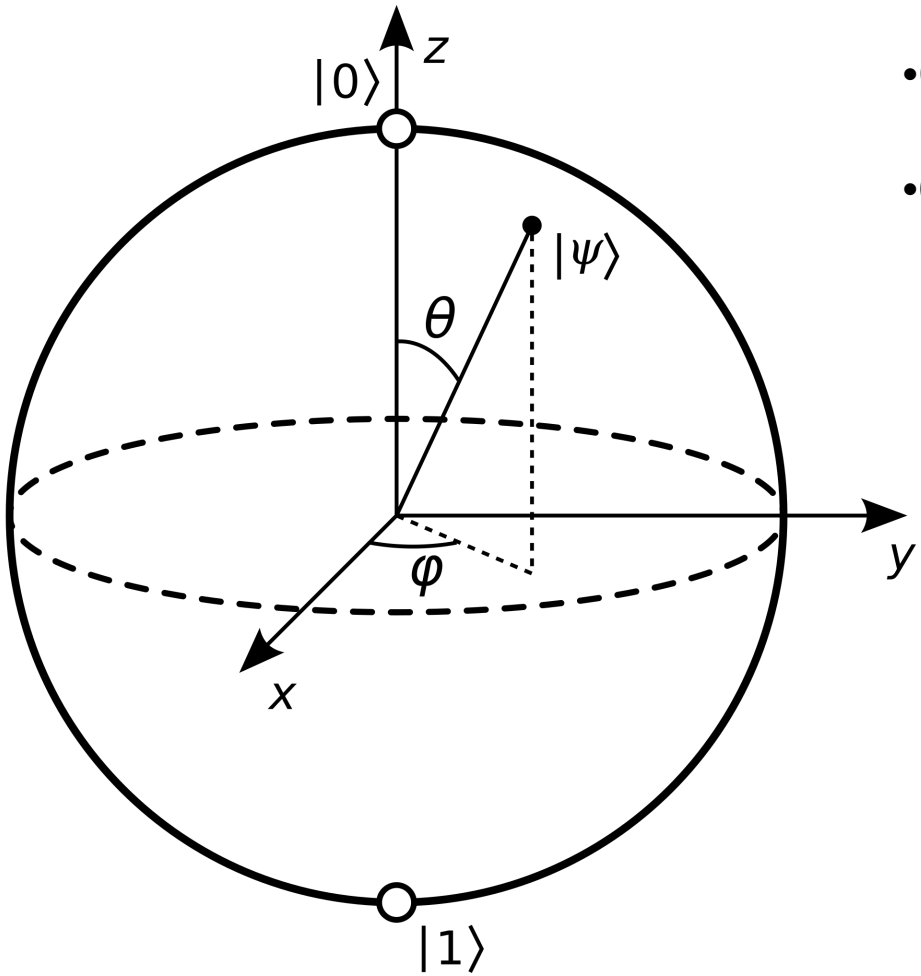
where
$|\alpha|^2+|\beta|^2=1$

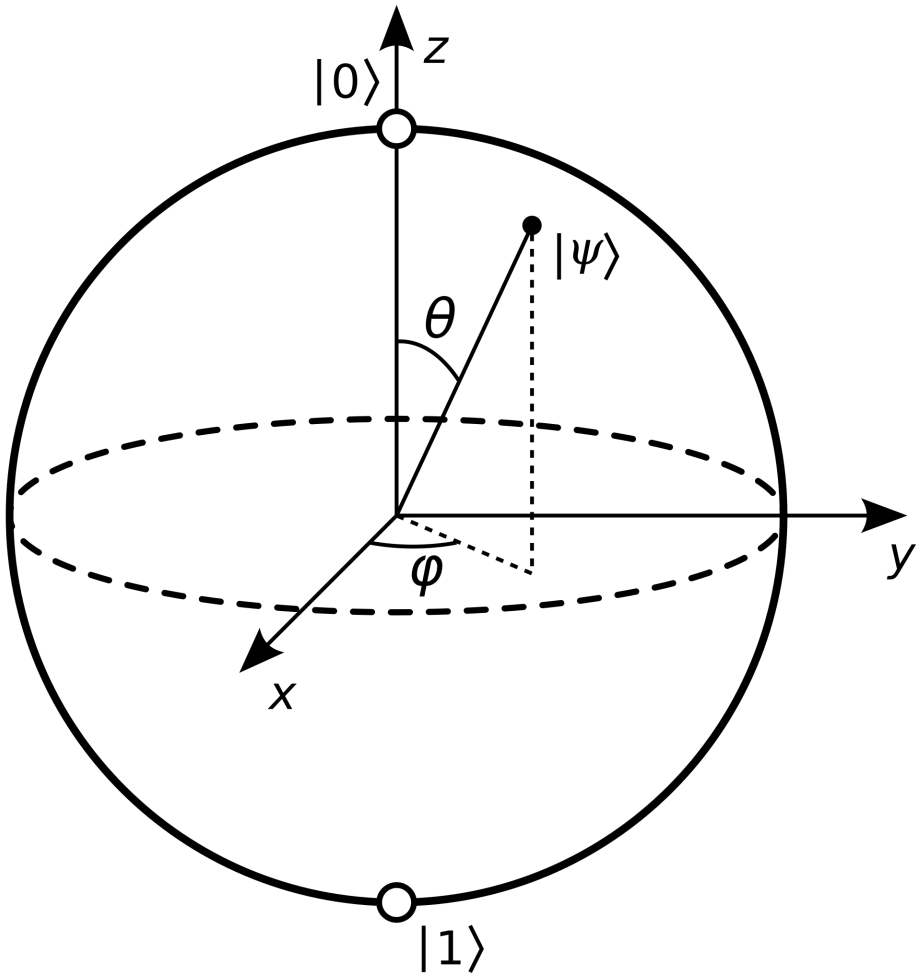
- **Superposition**
- **Measurement**

Quantum gates



- Classical logic gates (AND, OR, NOT) → manipulate bits
- **Quantum gates** → manipulate qubits using **rotations**

Quantum gates



Examples:

- **X gate** (like NOT): flips $|0\rangle \leftrightarrow |1\rangle$
- **Hadamard gate (H):** creates superposition

$$H|0\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

Quantum circuit model

A **quantum circuit** = sequence of **quantum gates** acting on **qubits**

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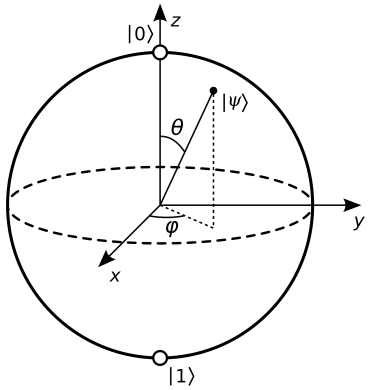

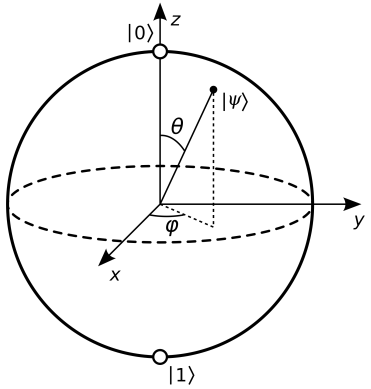

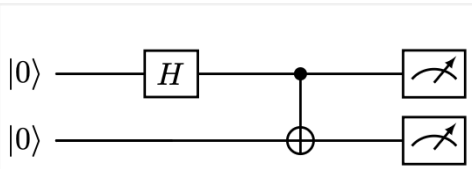

States (step-by-step):

$$|\psi_0\rangle = |0\rangle \otimes |0\rangle = |00\rangle\,,$$

$$|\psi_1\rangle = (H\,|0\rangle) \otimes |0\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}} \otimes |0\rangle = \frac{|00\rangle + |10\rangle}{\sqrt{2}},$$

$$|\psi_2\rangle = \mathrm{CNOT}\ |\psi_1\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}} \quad \text{(entangled Bell state)}.$$

Hybrid benchmarking of quantum algorithms

WHAT?

What does this even mean?

A framework for going beyond the asymptotic complexity of quantum algorithms

Quantifying Grover speed-ups beyond asymptotic analysis

Chris Cade[1,2], Marten Folkertsma[3], Ido Niesen[1,2], and Jordi Weggemans[3]

[1]QuSoft & University of Amsterdam (UvA), Amsterdam, the Netherlands
[2]Fermioniq, Amsterdam, the Netherlands
[3]QuSoft & CWI, Amsterdam, the Netherlands

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Eprint: arXiv:2203.04975v2
Doi: https://doi.org/10.22331/q-2023-10-10-1133
Citation: Quantum 7, 1133 (2023).

WHY?

Why should we even care?

General Linear Programming

Max Flow: Sending the maximum amount of water through a system of connected pipes from a reservoir to a city.

Vertex Cover: Placing the fewest security cameras on intersections so every road is monitored.

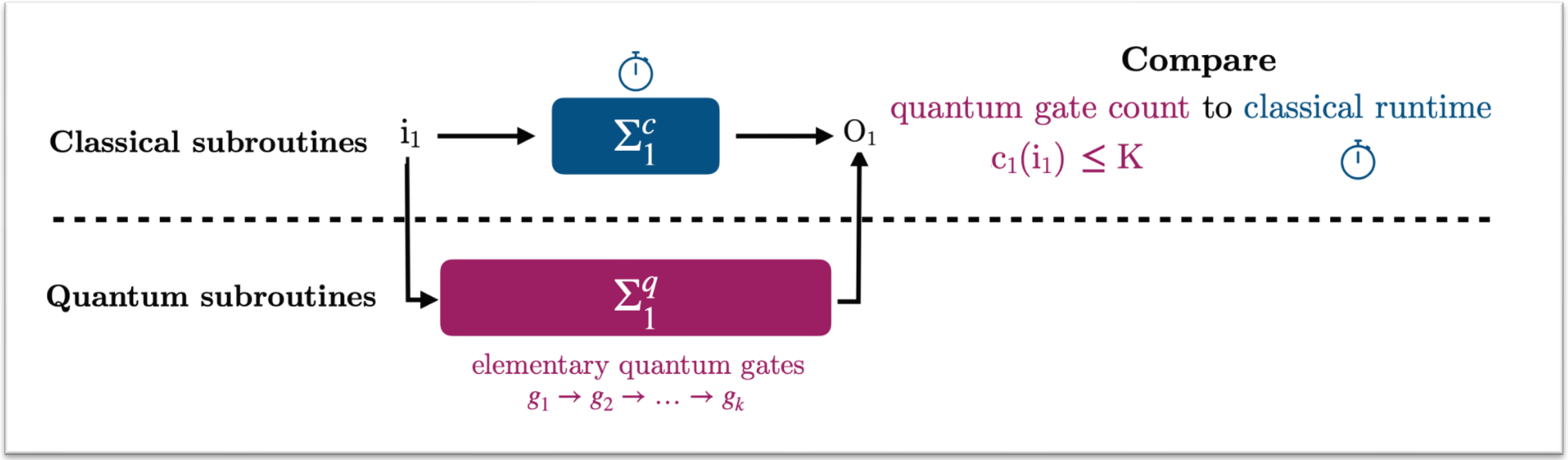
Independent Set: Choosing a group of employees for a task such that no two of them have a conflict (no edge between them).

Clique: Finding a group of researchers where every pair has co-authored a paper together.

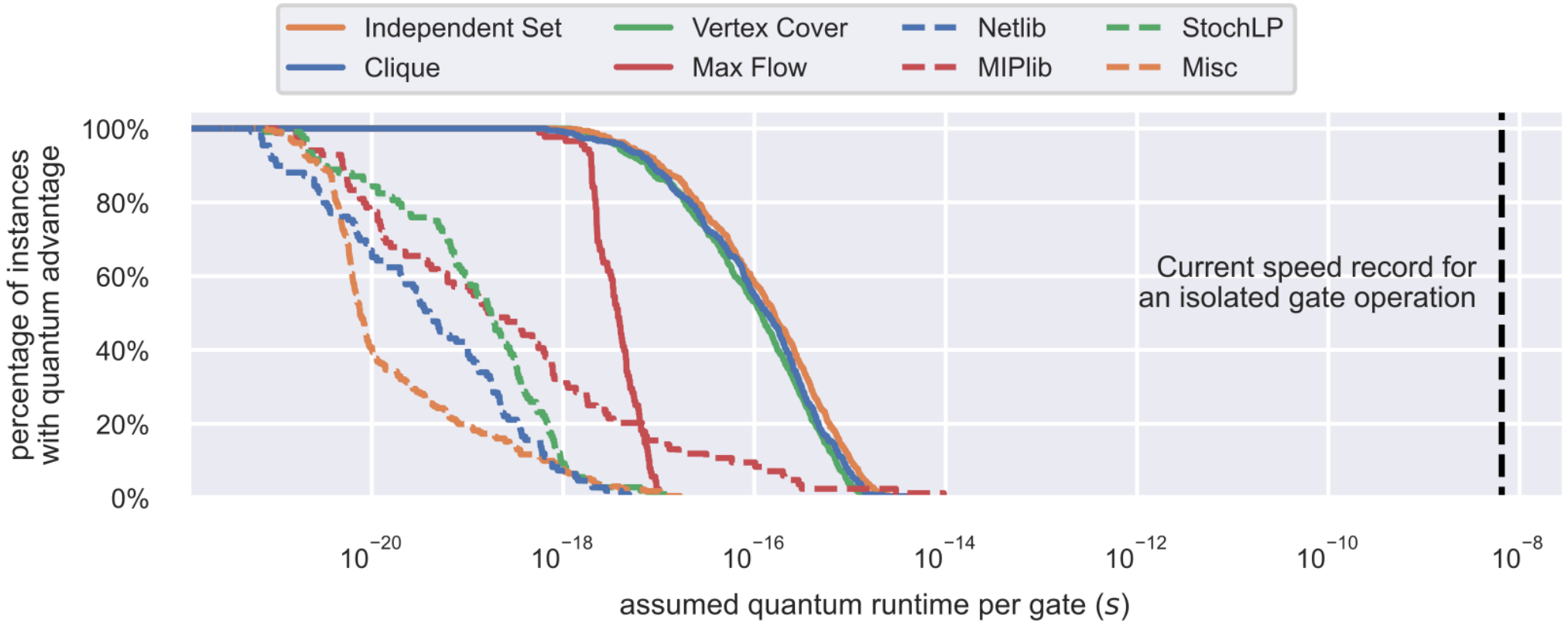
Realistic runtime analysis for quantum simplex computation

Sabrina Ammann, Sándor P. Fekete, Paulina L. A. Goedicke, David Gross, Maximilian Hess, Andreea Lefterovici,
Tobias J. Osborne, Michael Perk, Debora Ramacciotti, Antonio Rotundo, S. E. Skelton, Sebastian Stiller, Timo de Wolff

Gate Count


Classical subroutines
i_1
Σ_1^c
O_1
Compare
quantum gate count to classical runtime
$c_1(i_1) \leq K$
Quantum subroutines
Σ_1^q
elementary quantum gates
$g_1 \to g_2 \to \ldots \to g_k$

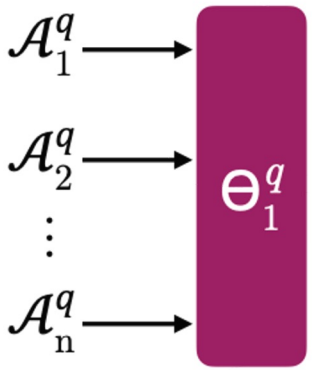
How many instances would be solved faster?



Beyond asymptotic scaling: Comparing functional quantum linear solvers

Andreea-Iulia Lefterovici, Michael Perk, Debora Ramacciotti, Antonio F. Rotundo,
S. E. Skelton, Martin Steinbach

Query Count

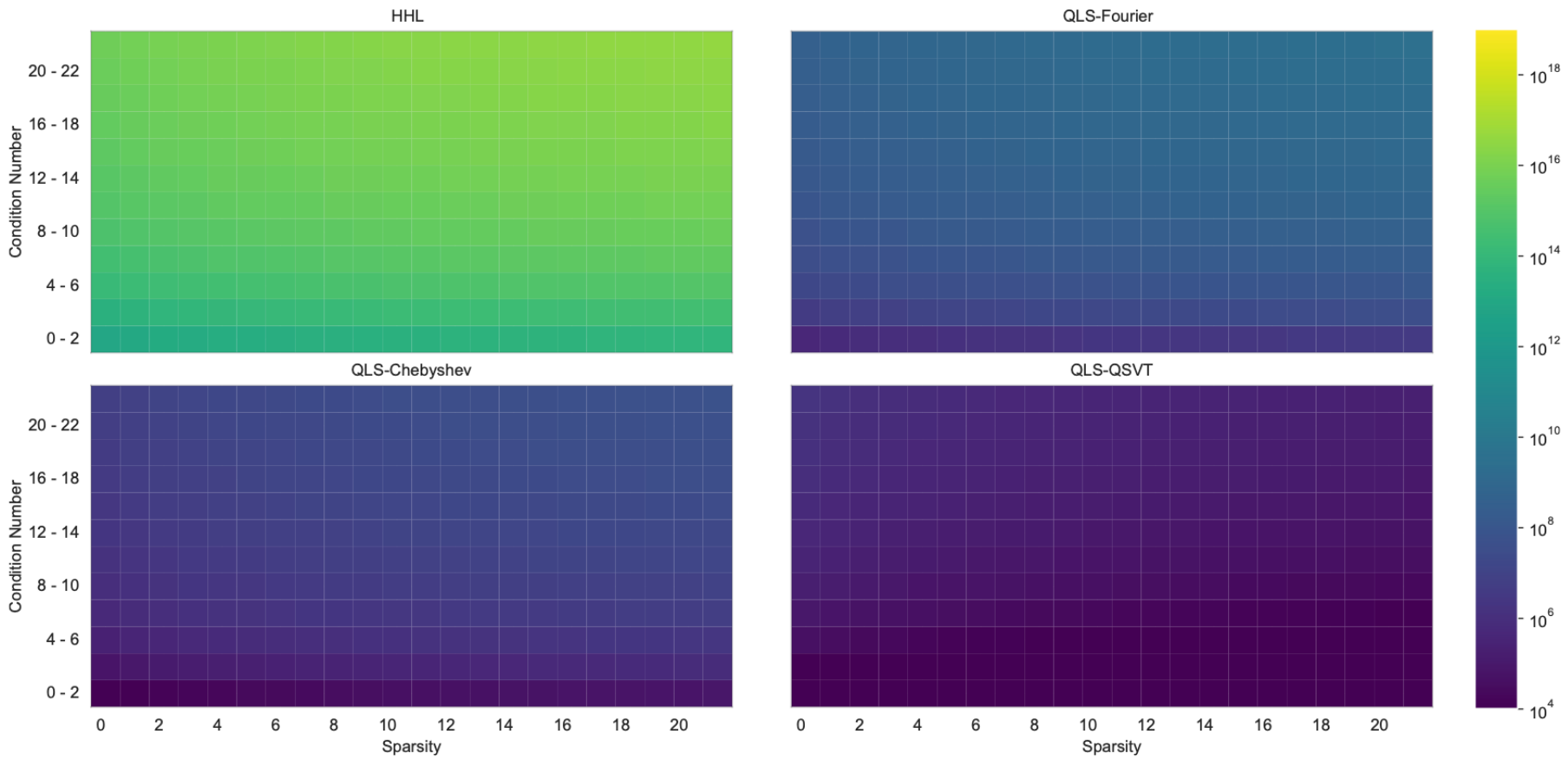


Compare

quantum query count of different quantum algorithms

$\mathcal{Q}[\mathcal{A}_1^q]$ to $\mathcal{Q}[\mathcal{A}_2^q]$ to ... to $\mathcal{Q}[\mathcal{A}_n^q]$

And… which QLS looks promising (on well-conditioned and sparse problem instances)?



A quantum algorithm for solving 0-1 knapsack problems

Sören Wilkening, Andreea-Iulia Lefterovici, Lennart Binkowski, Michael Perk,
Sándor P. Fekete, Tobias J. Osborne

0-1-knapsack problem

Problem parameters:

- capacity $c \in \mathbb{N}$
- item profit values $p_1, \ldots, p_n \in \mathbb{N}$
- item weights $w_1, \ldots, w_n \in \mathbb{N}$

Problem formulation:

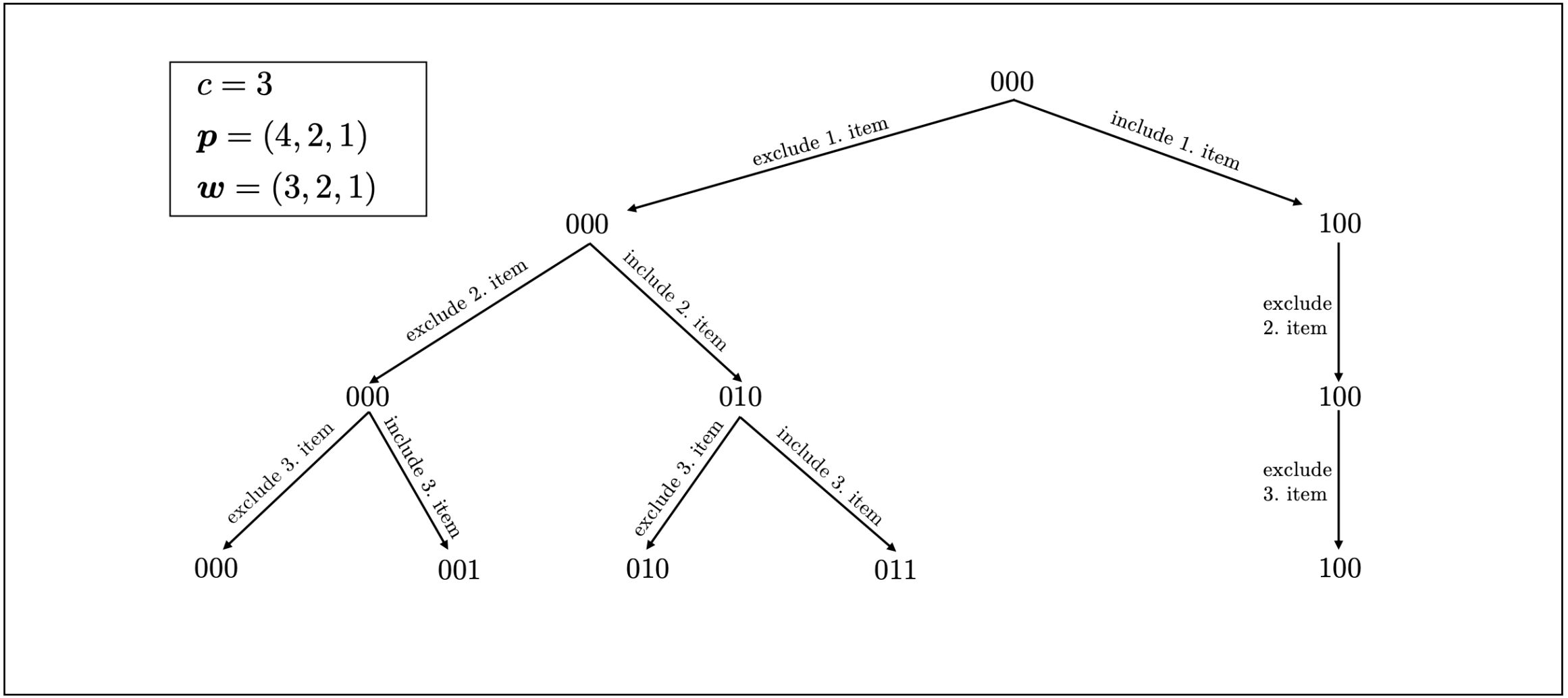
$$\text{maximise} \sum_{m=1}^{n} p_m x_m$$

$$\text{subject to} \sum_{m=1}^{n} w_m x_m \leq c$$

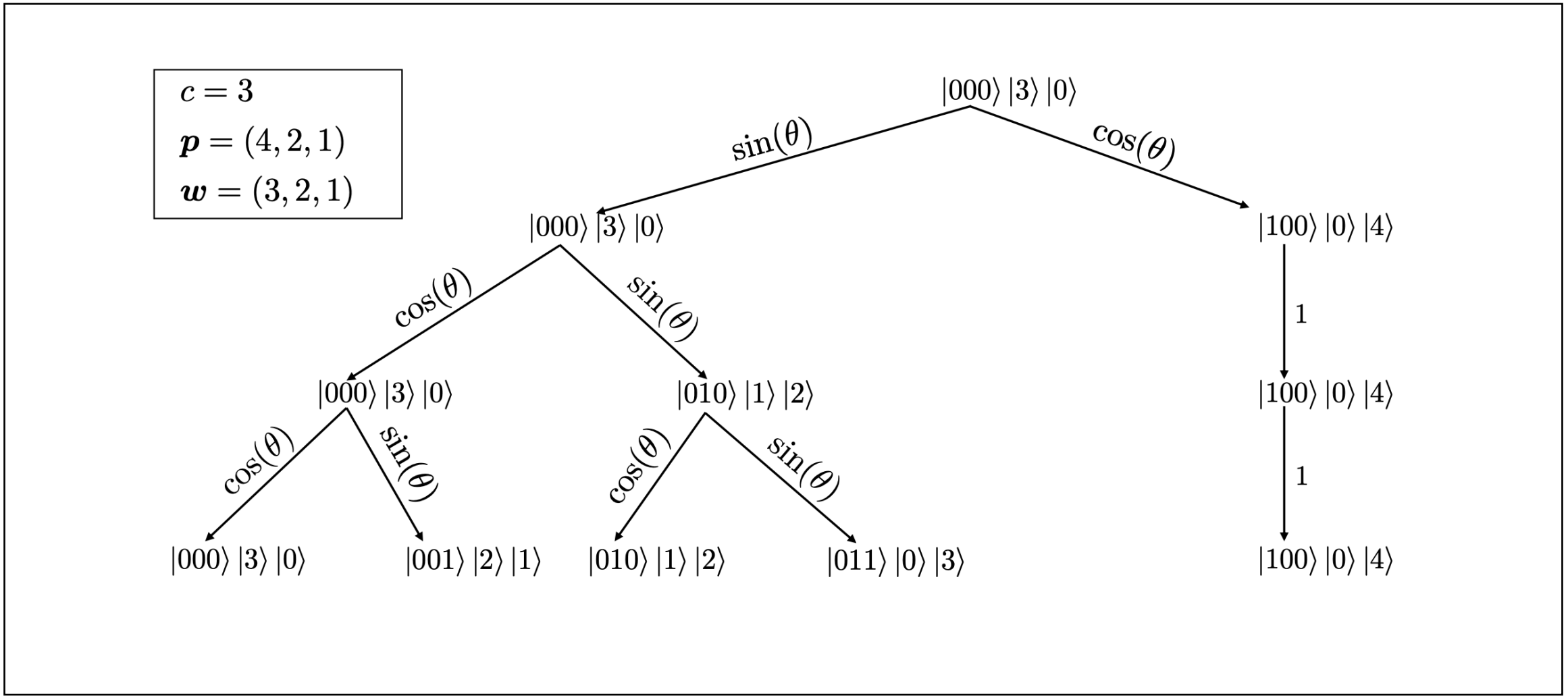
$$\text{and } x_m \in \{0, 1\},\ m = 1, \ldots, n$$

- NP-hard
- in practice rather easy to solve
- classical state-of-the-art: COMBO

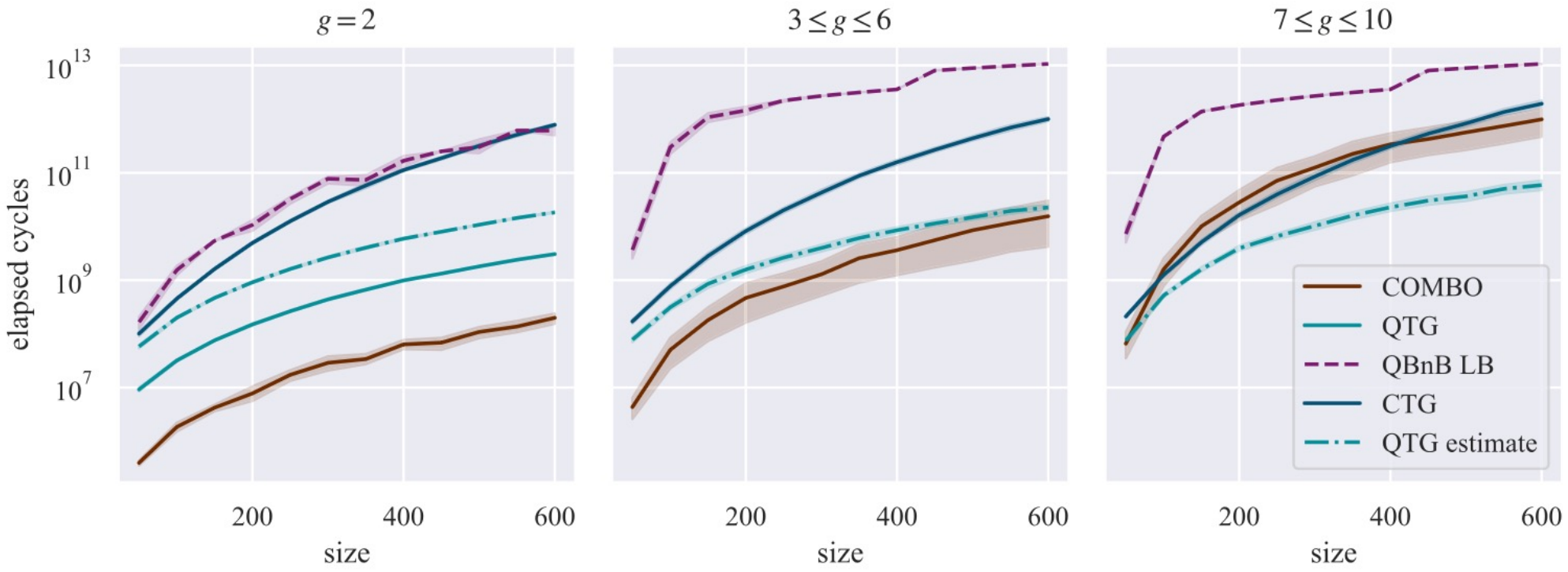
0-1-knapsack problem



QTG for 0-1-knapsack problem



Could that be a speed-up?



What do you do with these results?

- A start-up?

What do you do with these results?

- A start-up?
- But not the kind you might think of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