VINCI Energies' quantum computing journey

Phil Arnold, VINCI Energies, on behalf of the team

Hannover Messe | April 2025

Motivation | Vision

What a quantum computer is (not)

Our first quantum computing PoC: risks and benetifs

Quantum Technology Domains

Hybrid
(CPU/GPU/TPU & QPU)

Quantum Sensing[1]

- Quantum gravimeters

Quantum Communication

- Build and run high performance compute centers

Quantum Computing[0]

- Build and run high performance compute centers
- **Computational bottlenecks** (**comb opt**; ML / DL)

Pictures taken from here.
0: Currently only NISQ devices available
1: There might be a huge difference when comparing performance in lab VS real-word ATM!

Motivation

Combinatorial Optimization Space

Examples

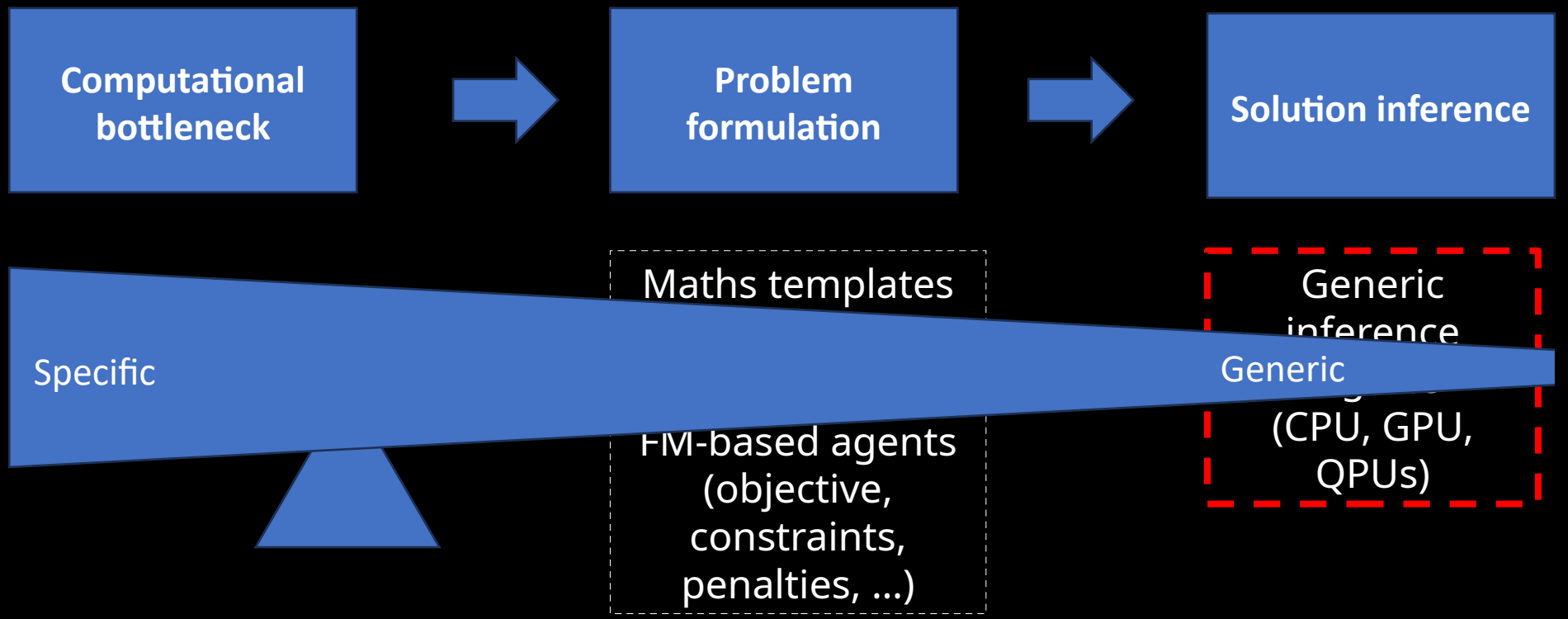
Logistics, supply chain optimization, flight gate assignment, allocate jobs, optimal way to deliver packages, optimal object placement

Challenges

Local properties not useful, discrete search space, non-convexity, complex constraints, NP hard, solution representation

Vision

Combinatorial Optimization Space

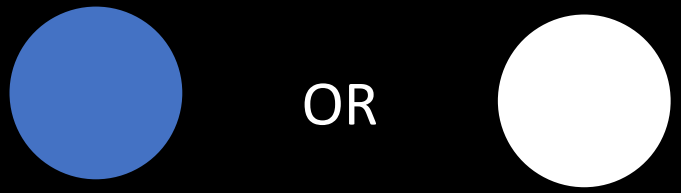


What is quantum computing (not)?

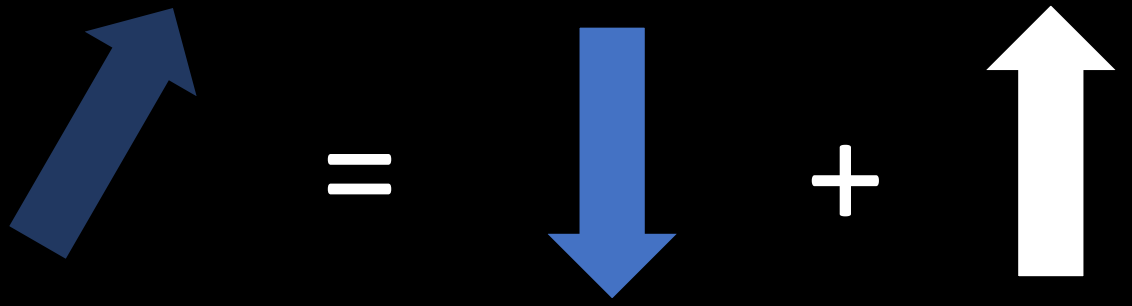
Conventional and quantum computers are based **on completely different principles**

BUT

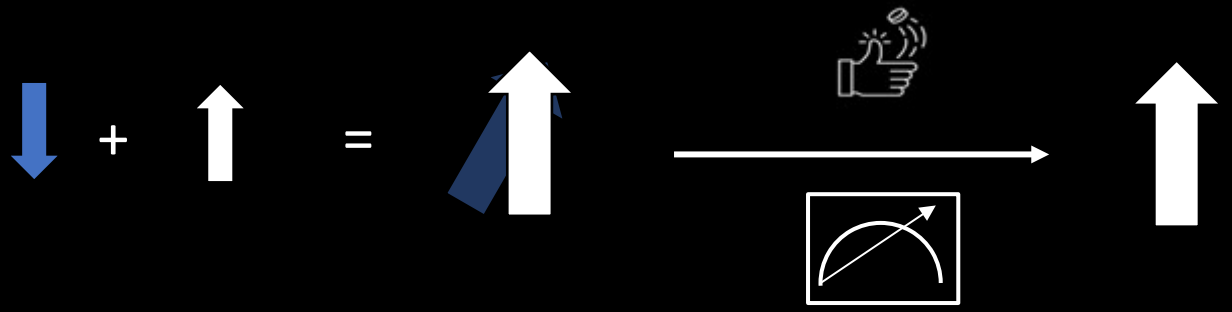
They have the **same computability.**



Either … or



Both
(Superposition)



(Almost) any measurement results in information loss[1]

1: Information you no longer have access to. Foundations of QMs: Copenhagen-like ➔ Collapse; Many worlds ➔ Branching + Decoherence

Entanglement

Lord of the rings trilogy VS quantum lord of the rings trilogy

1

2

3

Combine the best of the two worlds
–
hybrid computing

What might quantum computers be bad | good at?

What are conventional computers good | bad at?

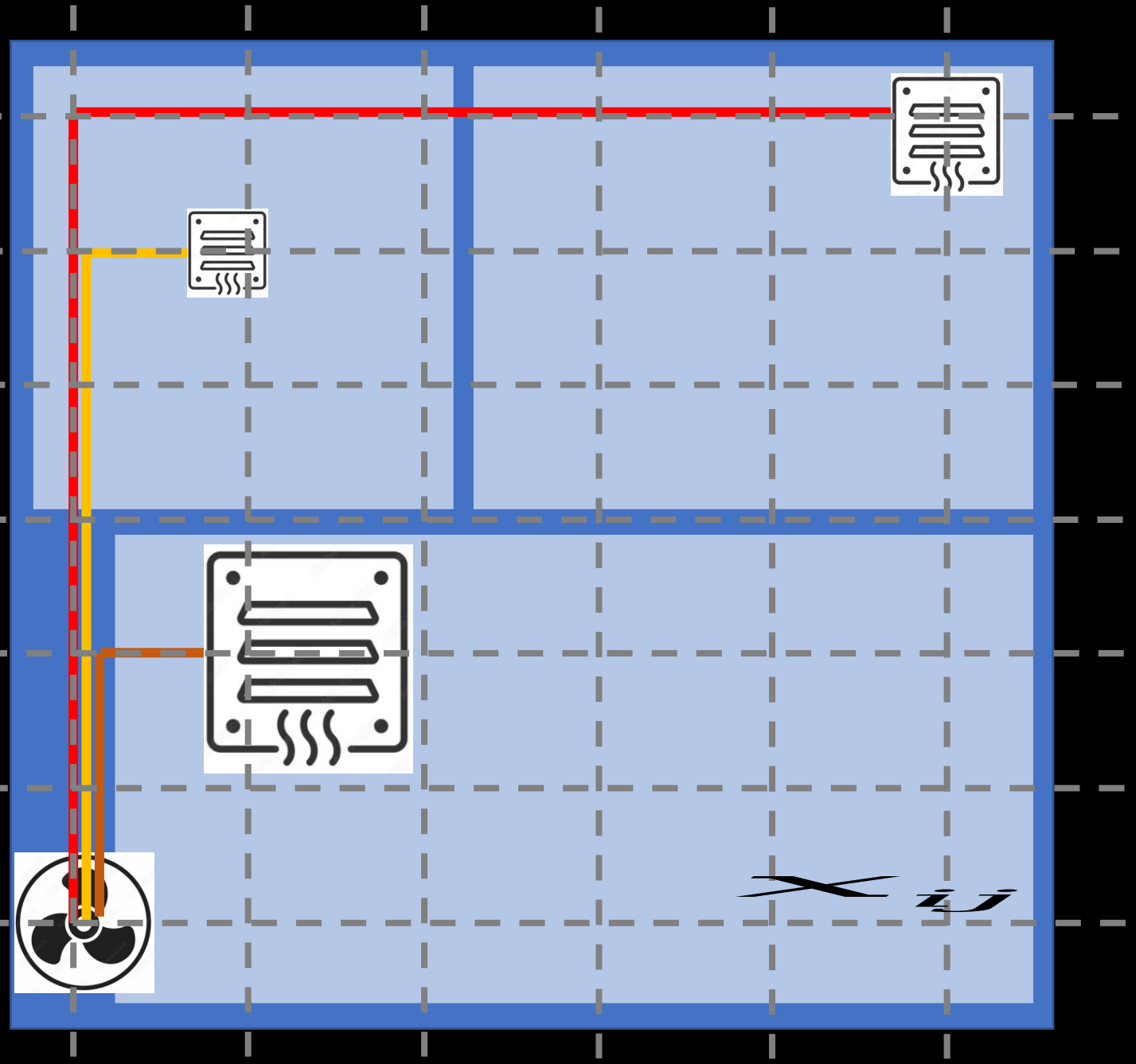
qcPoC: HVAC network generation

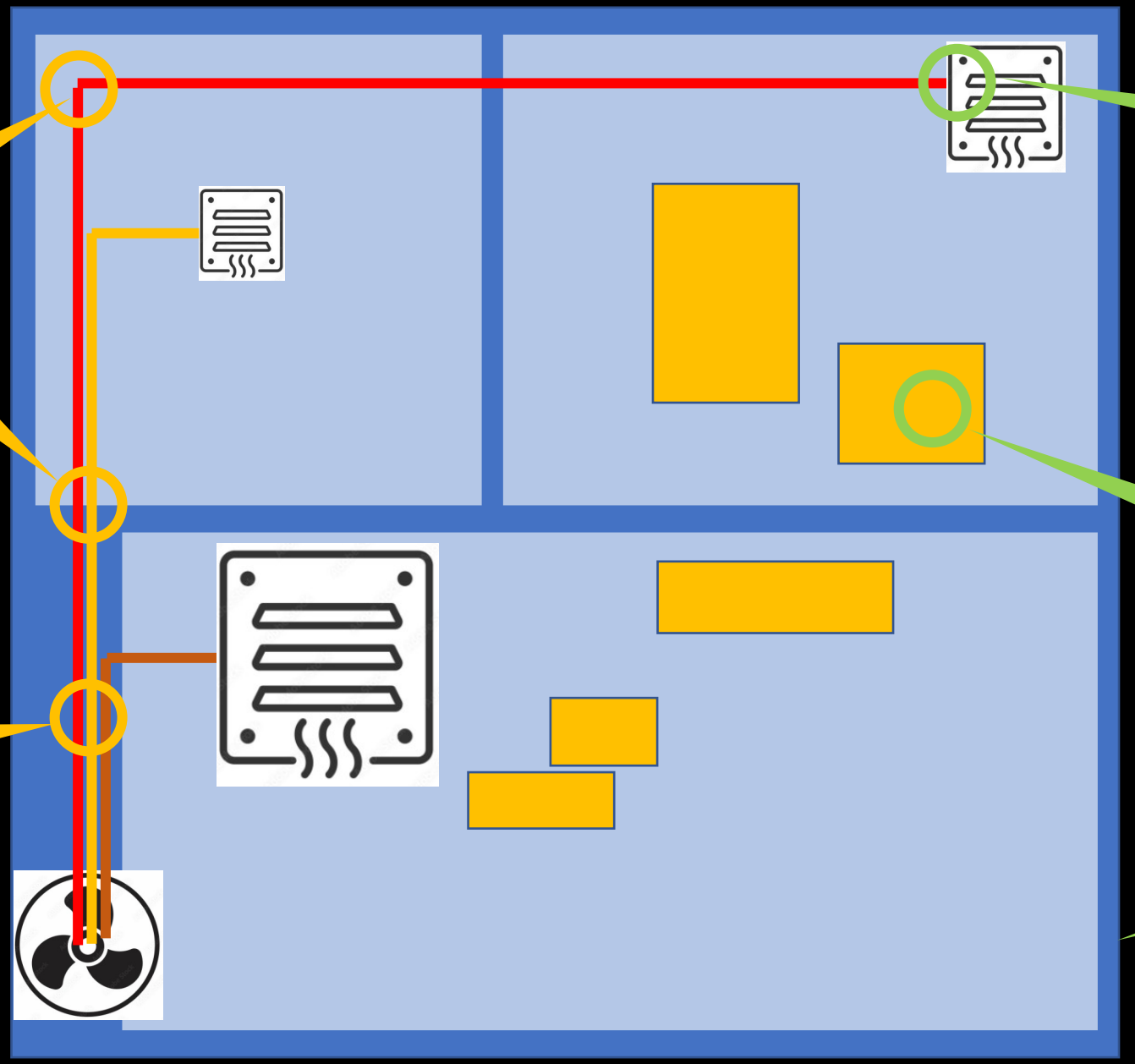
Stéphane Maviel, Cédric Lejay, Théo Delobelle, Simon Hofstetter, Andreas Hempel,

Sascha Baecker, Reinhard Schlemmer, Thorsten Haeberlin et al

Donya Hardan, Renu Ann Joseph, Robby Toole, Damir Bogdan et al

Austin Roberts, Jeffrey Fogel, Logan Lim, Victoria Goliber, Irwan Owen et al





Constraints to fulfill

Costs to minimize

Mathematical Formulation(s)

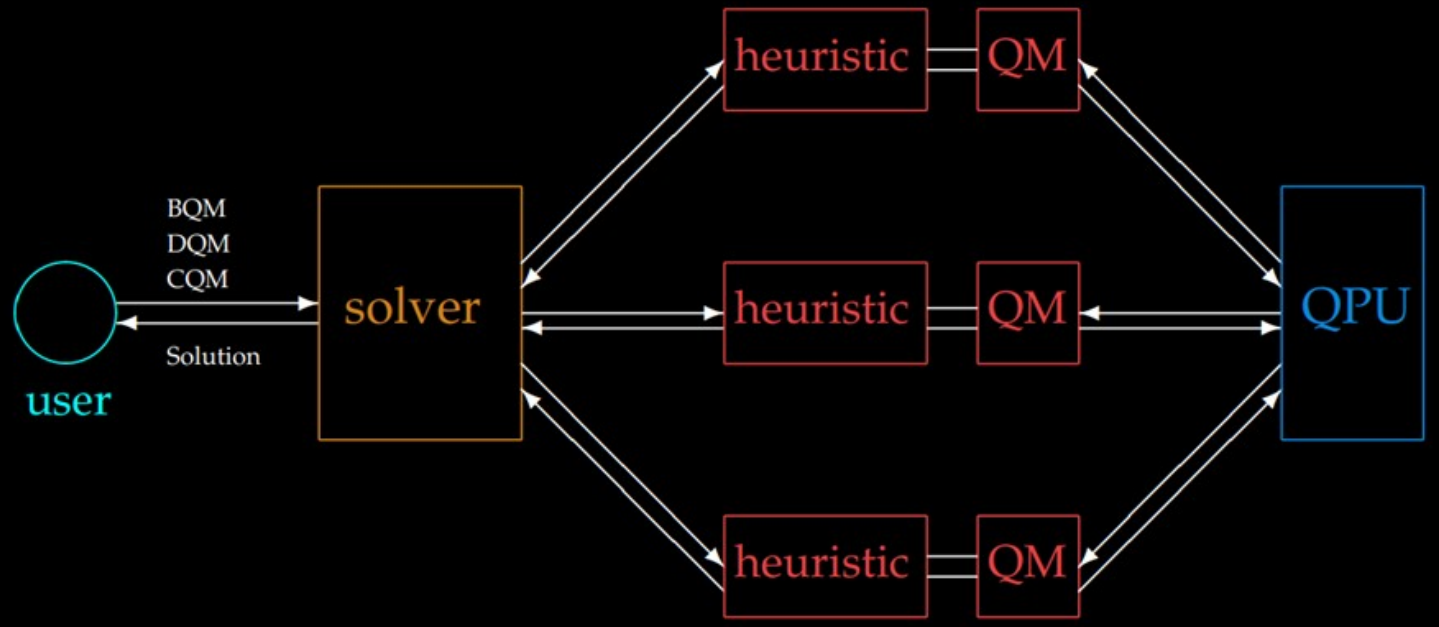
Minimize an **objective**

subject to **constraints**

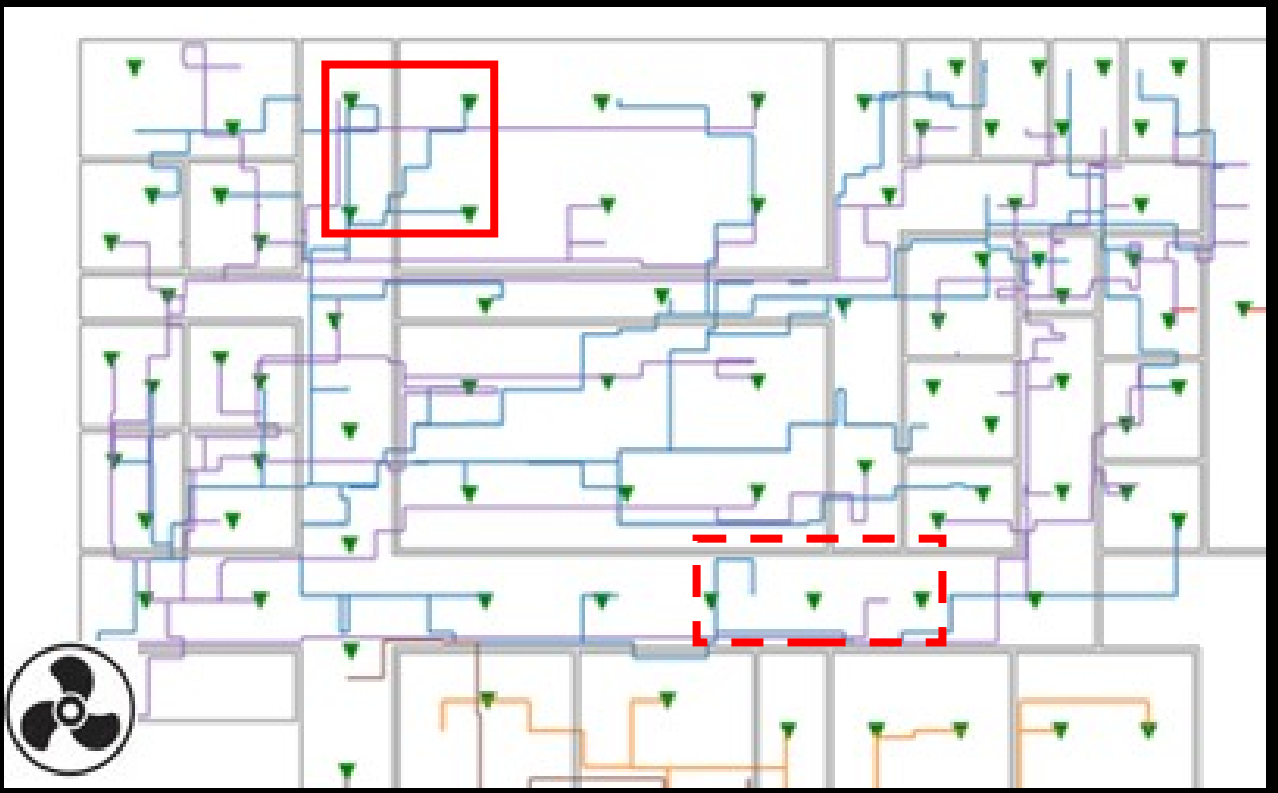
Problem size

HVAC System[1] [Name]	# Variables [in 1,000s]	# Constraints [in 1,000s]
Return CTA	19	5
Return CTA2	27	6
Return CTA3	29	8
Blow CTA	40	9
Blow CTA2	45	10
Blow CTA3	46	11
Blow CTA4	56	15

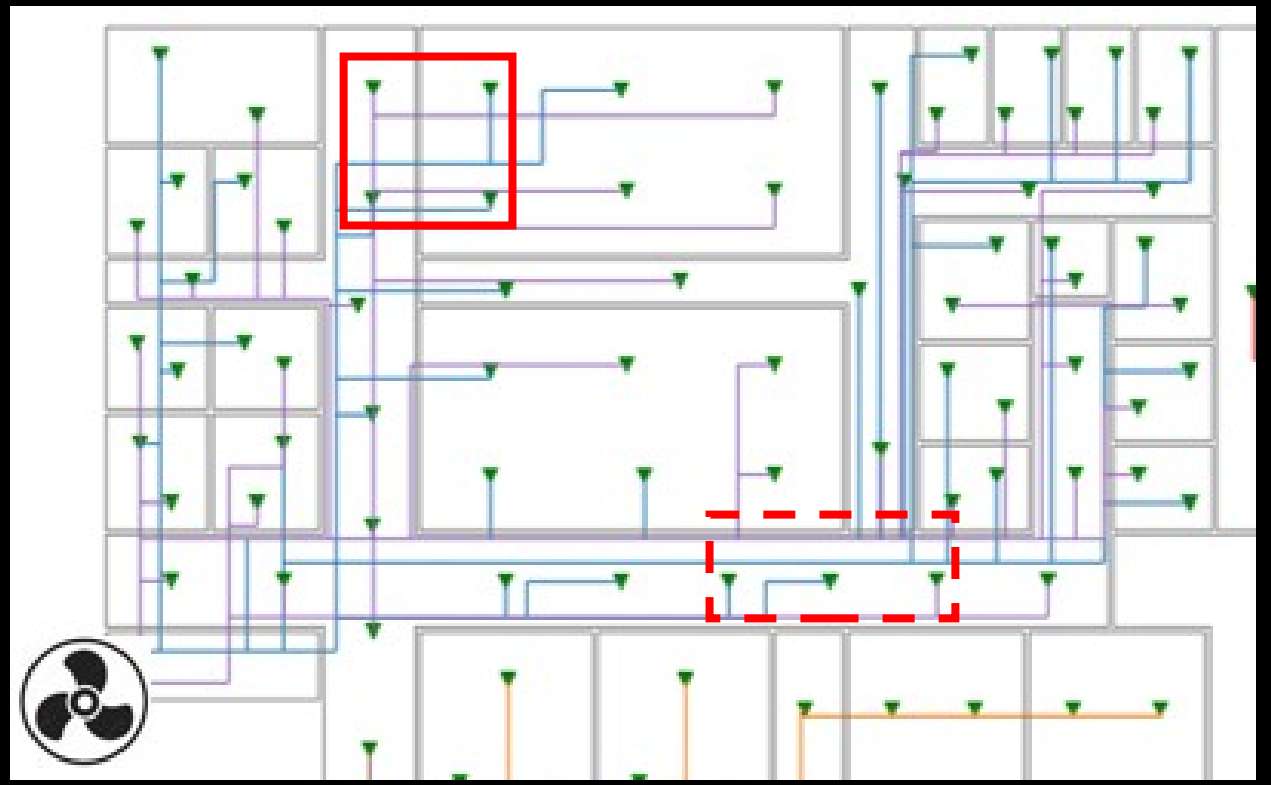
D-Wave's latest hybrid solvers



Baseline solution

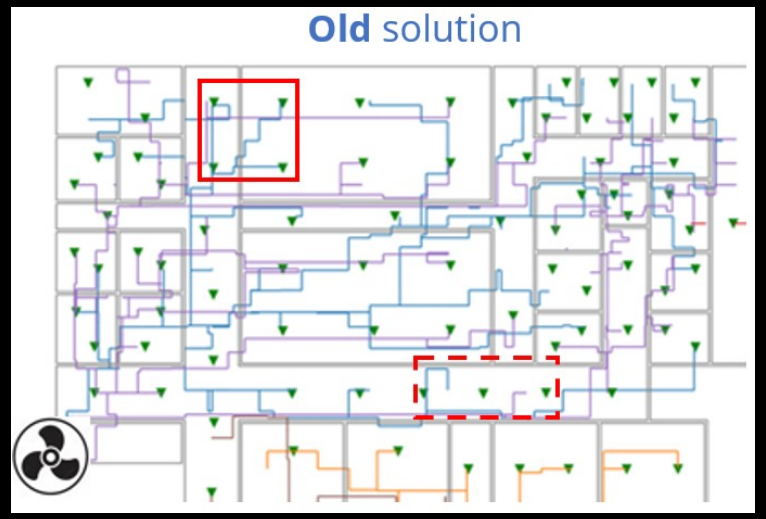


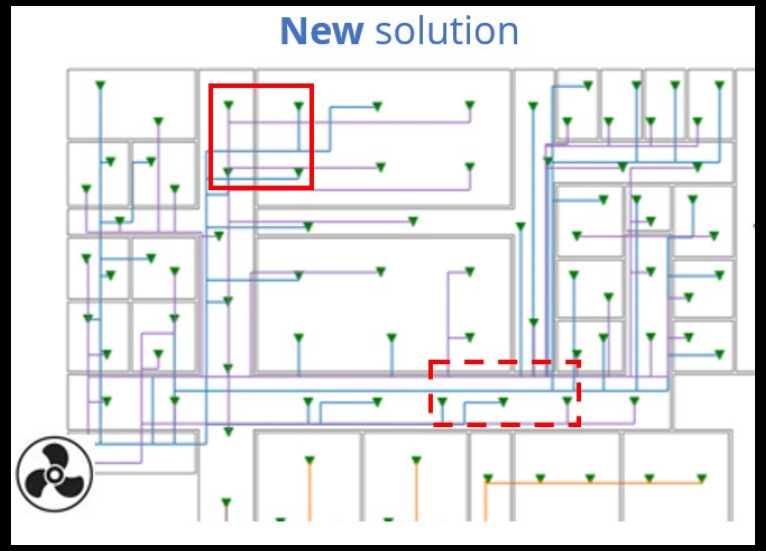
New solution



Assessment of quality by HVAC SMEs (subjective judgment)

Quantitative[0] Results





The new <u>solutions</u> are **more optimal** based on:

- Material cost: length, volume, number of Ts and elbows, …
- Construction cost + Aesthetics : number of room crossings, …

The new <u>approach</u>

- Finds solution **much more quickly**[1]
- Is **much more scalable**[1]

We have <u>not</u> (yet)

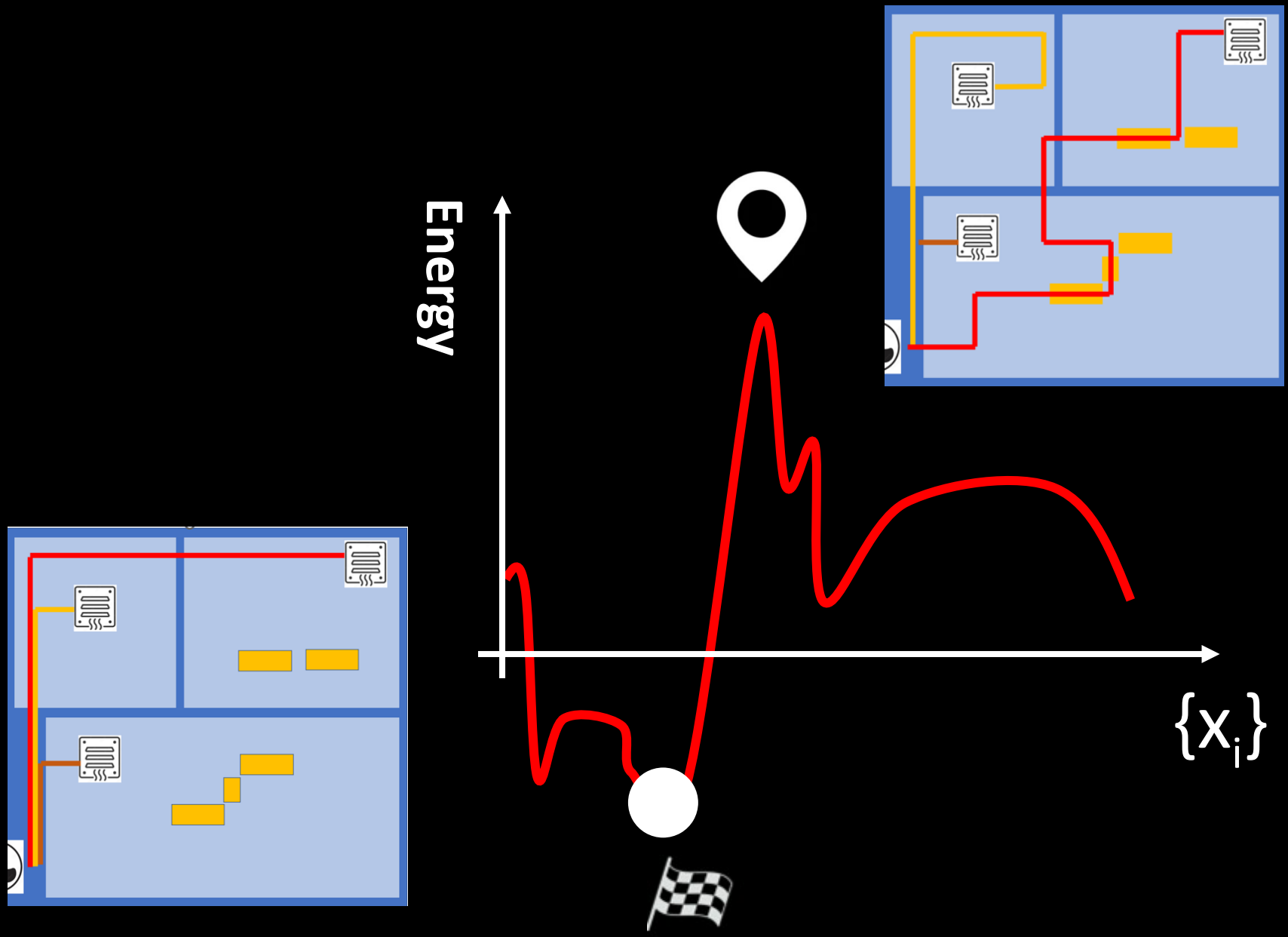
- Disentangled performance improvements: **Formulation VS D-Wave's hybrid solvers** (heuristics VS quantum annealing part[2])

0: We have proper estimates [%], but I'm not allowed to show them.
1: Compared to vanilla MIP (Mixed Integer Programs) solvers (CQM formulation) and tools in production.
2: For example, we did not investigate hybrid acceleration as described in D-Wave's whitepaper "Hybrid Solvers for Quadratic Optimization" (link)

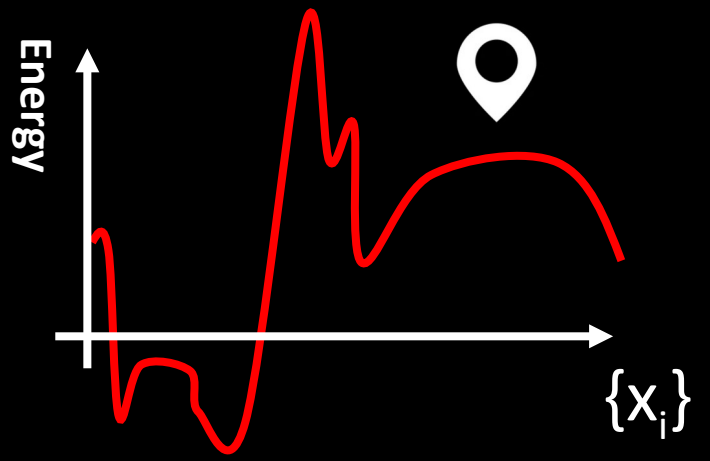
Last but not least …

-

Why might quantum computing be beneficial for (certain) combinatorial optimization problems?

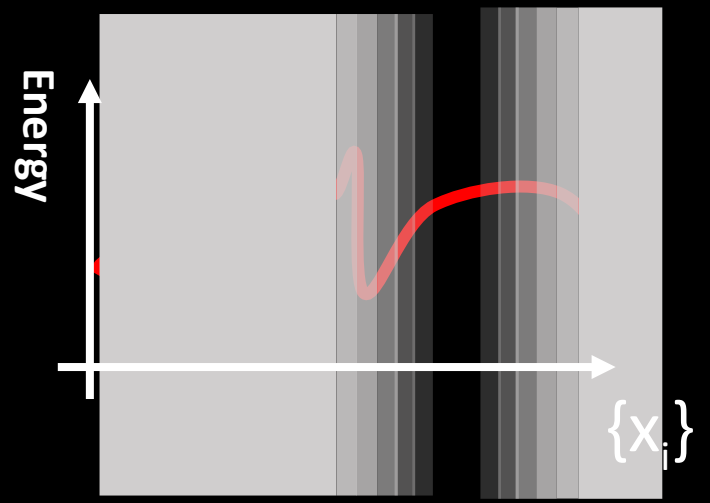


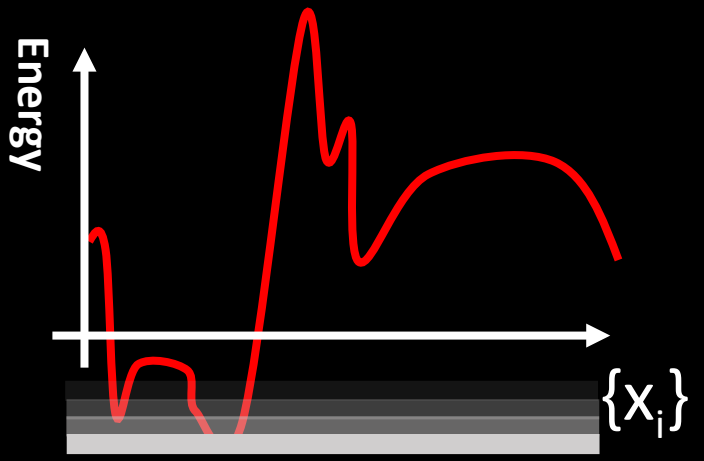
NOTE: Not a continuous energy landscape but a **discrete** one!!!



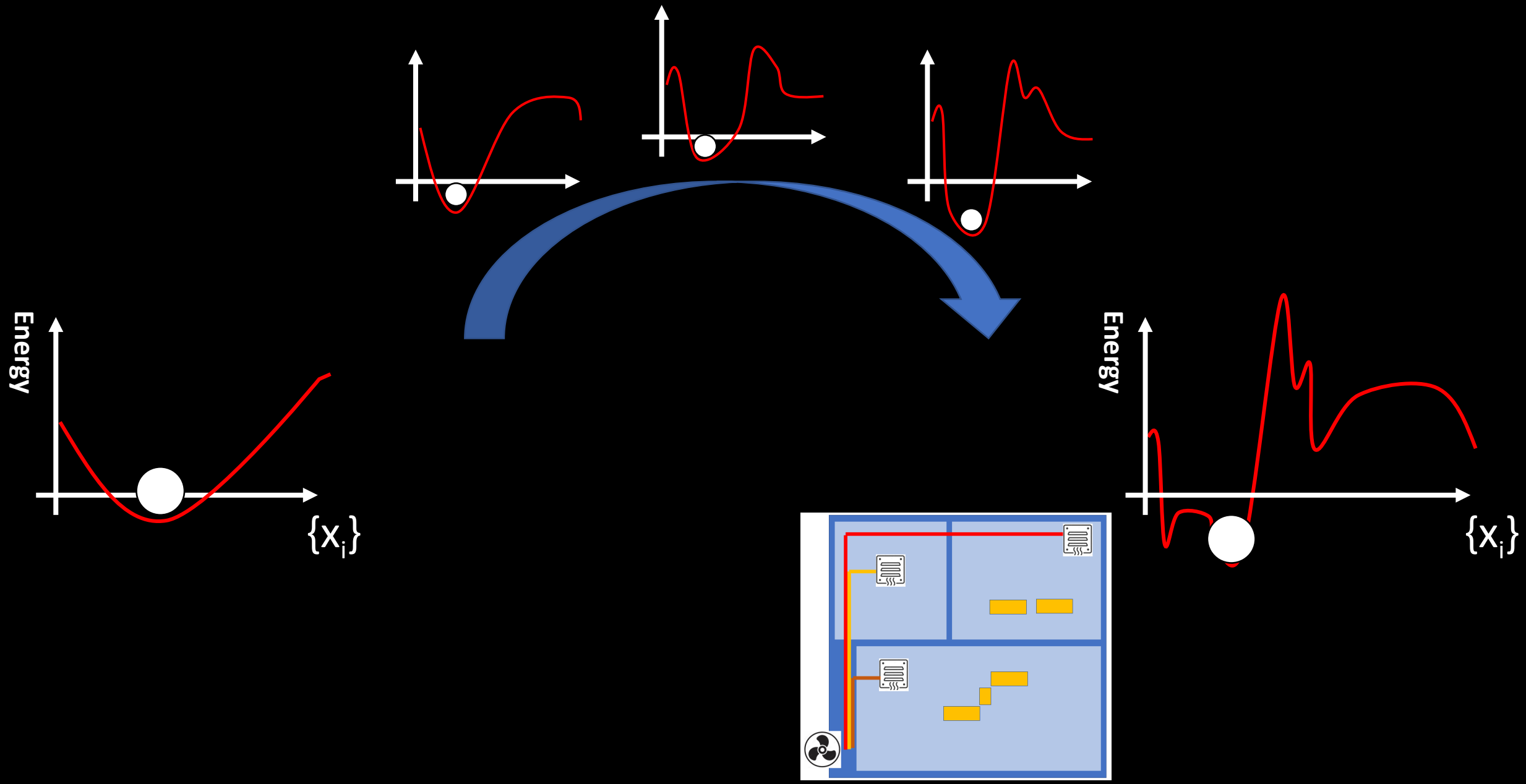
CPU, GPU

AQC / QA





Under **certain assumptions** and
given **certain conditions** (problem dependent) we can
get a pretty good bird's eye view on the problem


Energy
$\{x_i\}$
Energy
$\{x_i\}$

Thank you!

-

Questions?

Thank you …

Questions?

Thank you …

Questions?

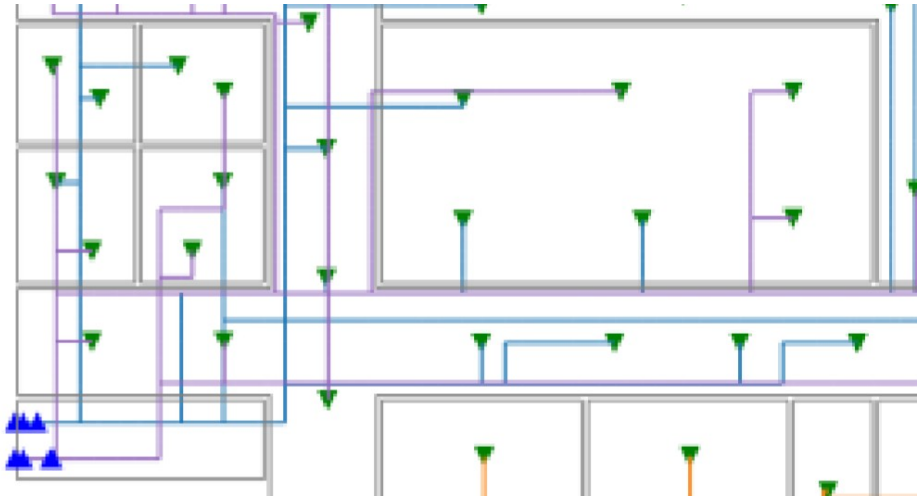
Quantum Mechanics

Conventional and quantum computers are based **on completely different principles** (Boolean logic VS quantum mechanics)

Problem Description

NOTE: HVAC network generation was selected as this is a **challenging computational bottleneck** for VINCI Construction and, at the same time, allows the generation of insights for strategic adjustments.

- Context
  - We need to build an HVAC system in a new building.
  - We need to choose where to build ducts.
- Goal
  - Find the lowest-cost network that provides the
  - required airflow to each room.
- How?
  - Choose where to place ducts from a large set of options.
  - Choose the size of each duct.



Slide and figures from qcPoC presentation (VE, D-Wave, QuantumBasel) – modified by Phil Arnold

Optimize problem formulation for quantum annealing and D-Wave hybrid solvers

Quadratic expressions

Allows for more complexity and expressiveness through interactions

Binary and discrete variables

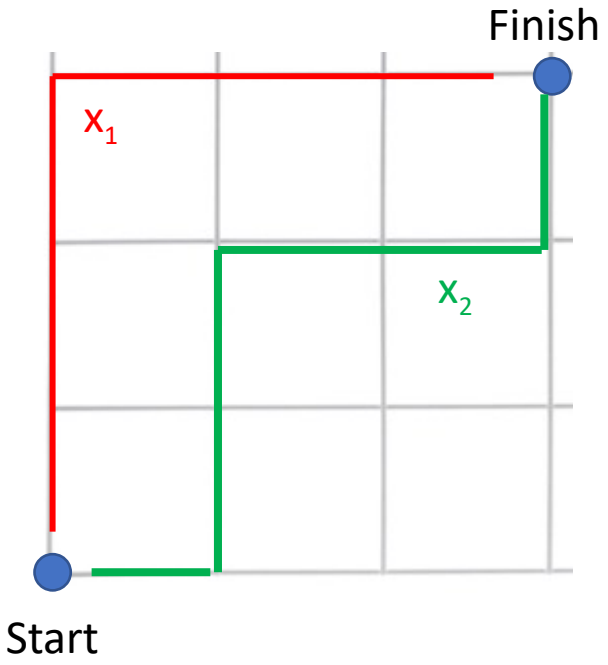
Many decision-based problems live in this domain

Challenging

Most solvers struggle with quadratics and binary/discrete problems

May depend on the scale of the problem & formulation

$$\min_{\mathbf{x}} \sum c_i x_i - \sum c_{ij} x_i x_j$$



Pick shortest path from start to finish from collection of paths {x1, x2}.

$$x_i \in \{0, 1\}$$

$$x_1 + x_2 \leq 1 : \text{constraint}$$

$$\propto x_1 \cdot x_2 : \text{penalty}$$

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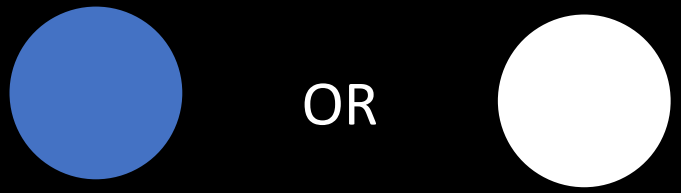
Note: see list of QUBO formulations here

Note: example is for explanation only! It does not make sense to implement it in this way!



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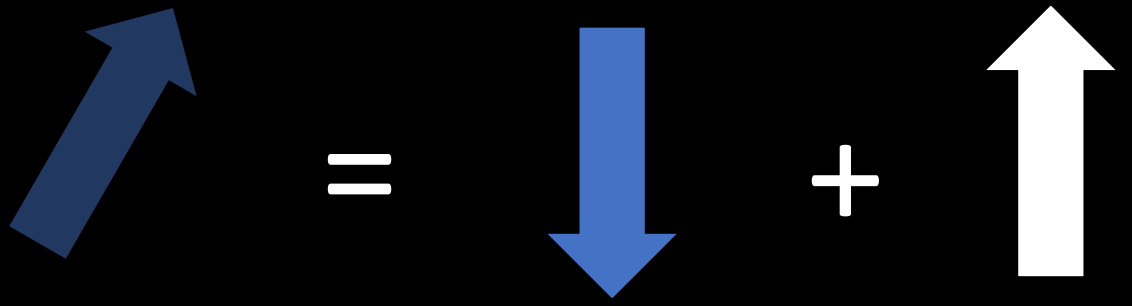


Both
(Superposition)

Entanglement

Lord of the rings VS quantum lord of the rings

1

2

3

983

Multiplication: Easy

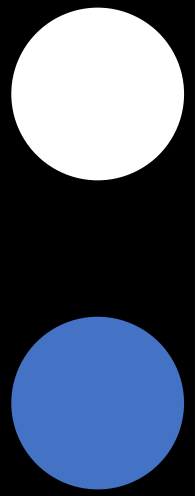
Factorization: Hard(?)

What a quantum computer is (not)

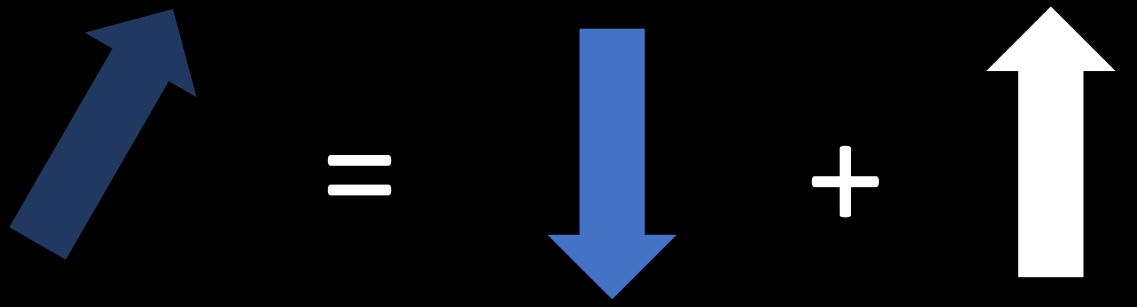
Conventional and quantum computers are based **on completely different <u>principles</u>** (Boolean logic VS QMs)

They have the **<u>same</u> computability but <u>different</u> strengths and weaknesses**

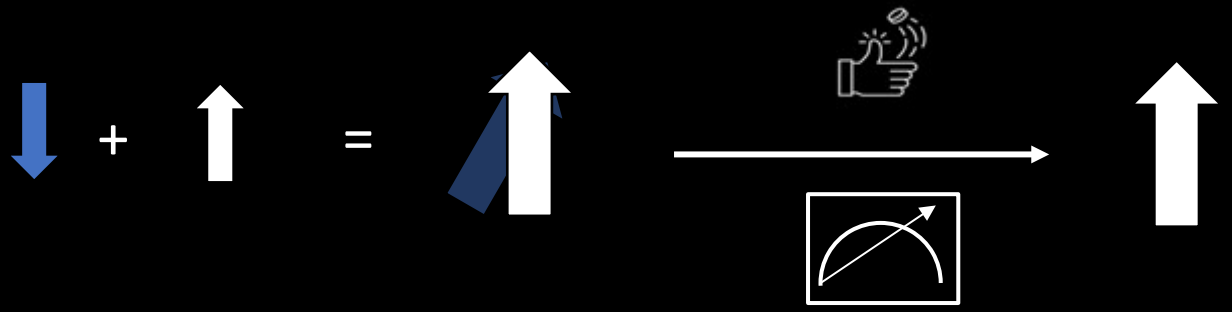
Future of computing is most likely conventional or **<u>hybrid</u>**



Classical bit in one of two states



Quantum bit in superposition



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