Objectivity
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Quantum and Quantum-inspired Annealing

The state of play

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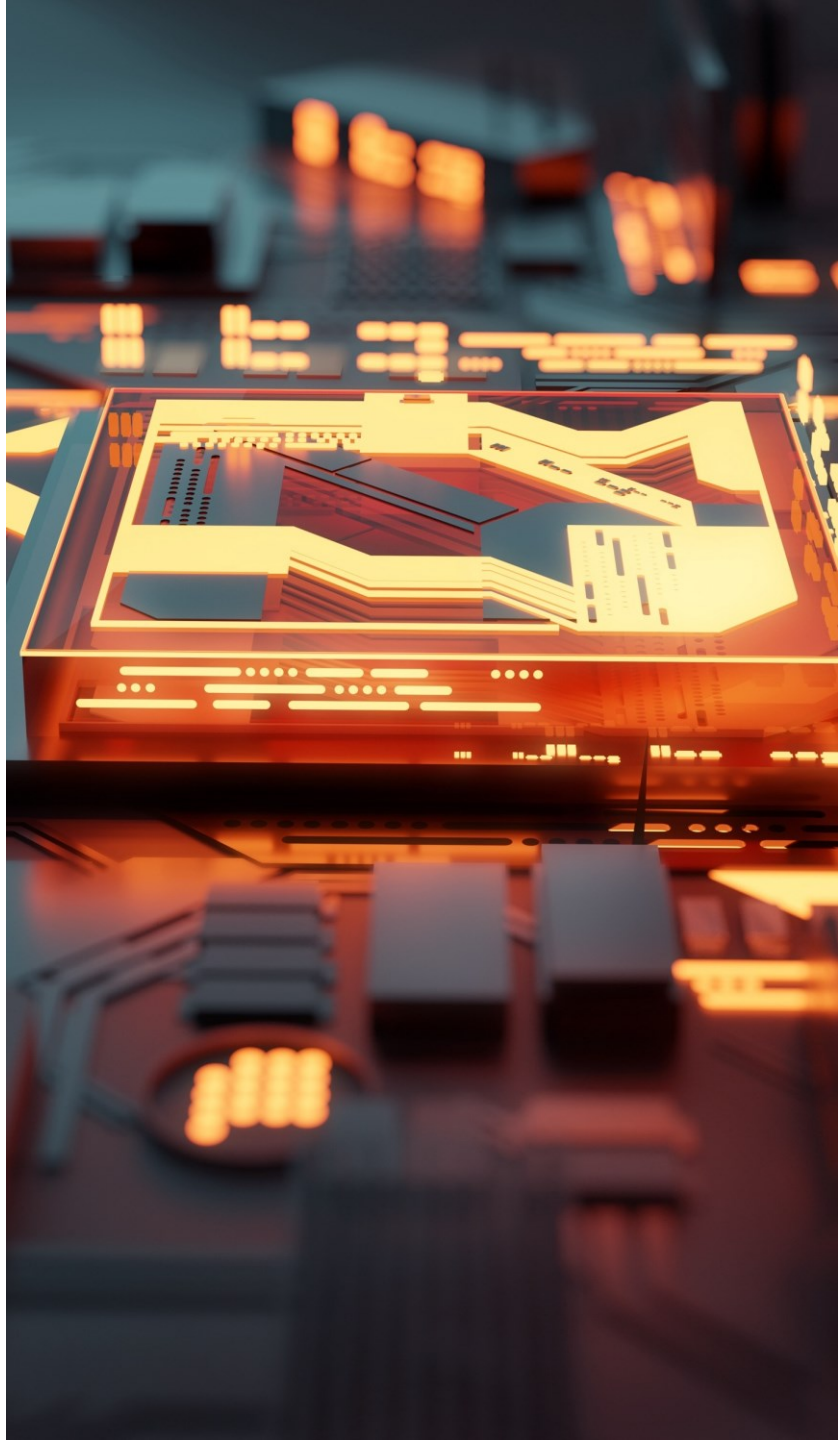


Who am I

Peter den Haan

Quantum Computing Specialist

BA (Oxon), PhD (Nijmegen)
on *aspects of quantum electrodynamics in AdS space*

12 years full stack development experience

1. Short introduction

A new way of conducting computations

Quantum vs classical approach

In theory quantum computing should be faster… if you can take advantage of entanglement

Quantum

Classical

The quantum ecosystem

- 48% believe quantum computing will play a significant role in their industries by 2025. The vast majority (97%) think quantum will disrupt their industries—as well as the UK economy—to at least some extent by 2027. *—EY / Jun 2022*
- 43% of organisations working on quantum technologies expect them to become available for use in at least one major commercial application with the next 3-5 years *—Capgemini / Mar 2022*

Hardware vendors

Microsoft, Google, intel, hp, Alibaba Group 阿里巴巴集团, D-Wave The Quantum Computing Company™, IBM

Early adopters

AIRBUS, Goldman Sachs, BMW, BBVA Banco, BNP PARIBAS, COMMERZBANK, Volkswagen, CRÉDIT AGRICOLE, Coca-Cola, TOYOTA, PayPal, Scotiabank, Pfizer

The predictions of useful quantum computing are different — from “now” up to “20 years or more”

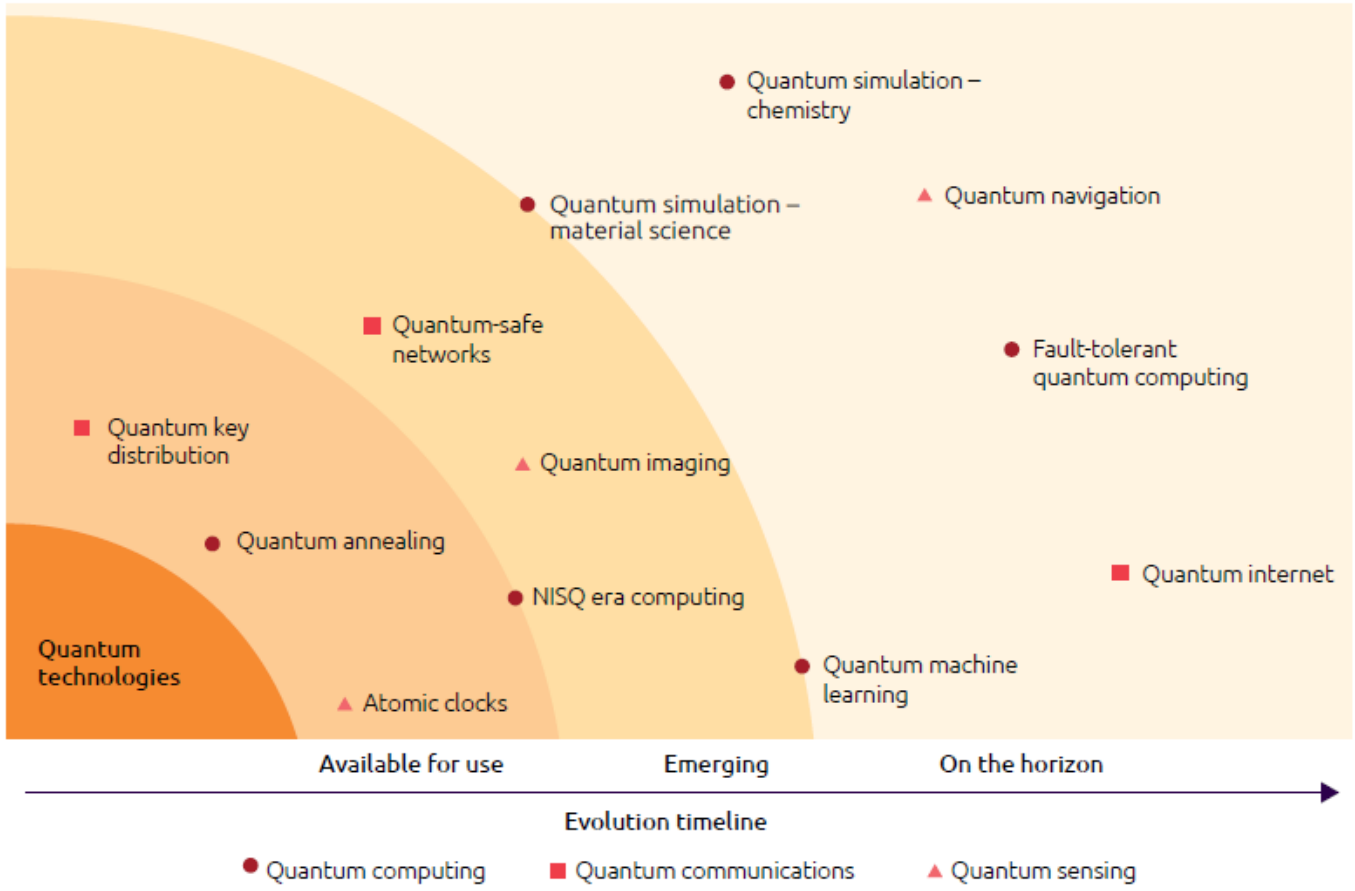
It depends on

- the use case
- the technology
  - circuit based
  - annealer based
  - quantum inspired

Likely evolution of quantum tech

key use cases

- For selected use cases we can see the first commercial usage of quantum computing.
- For more sophisticated ones, we need to have better hardware



Source: Capgemini Research Institute analysis.

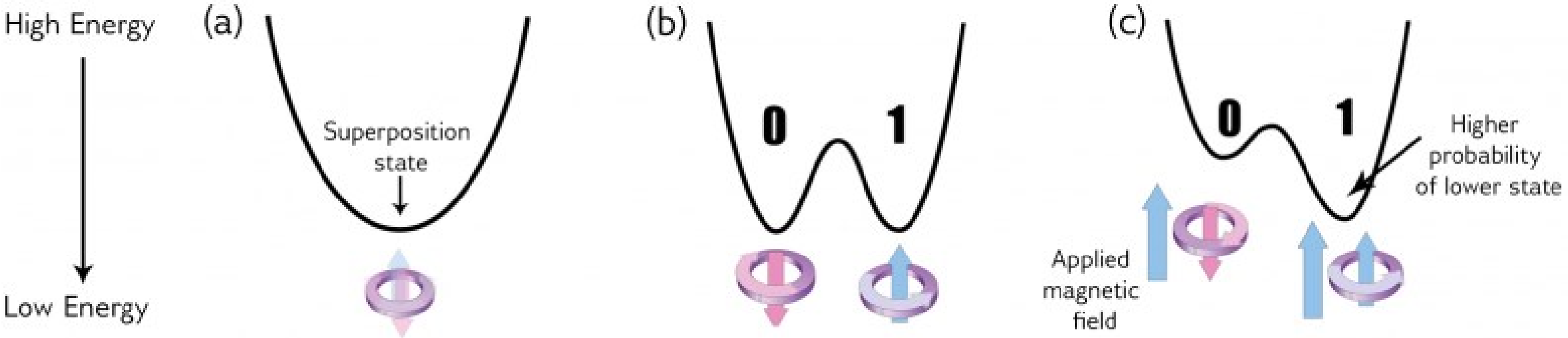
2. Annealers, the state of play

An overview of the market

Annealers

Restrictive but more mature

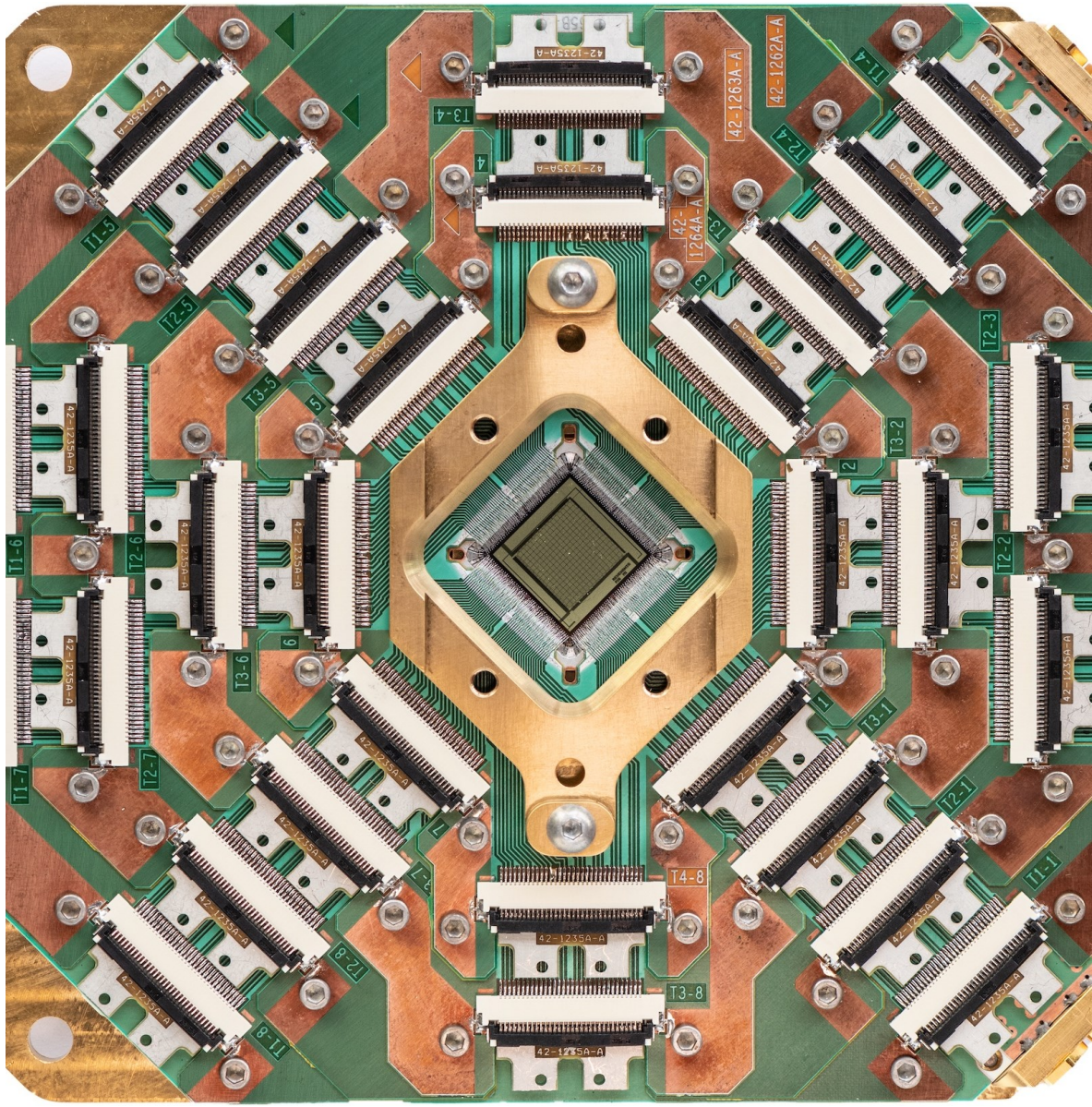
- Optimisation problems only
- Adiabatic theorem



Annealers

Characteristics

- Tunneling (Nature, arXiv:1411.4036v2)
- Entanglement (Phys Rev A **92**, 062328)
- No rigorous proof of superiority
- A surprising number of problems can be formulated as optimisation problems (Front. Phys. 12)
  - Including all of Karp's 21 NP-complete problems
- 5614 qubits (D-Wave)



Quantum vs Quantum inspired

D-Wave
The Quantum Computing Company™

TOSHIBA

1QBit

FUJITSU

Microsoft

LightSolver

Quantagonia

3. Benchmarking

Where the rubber hits the road

Rationale and approach

- Near term use of quantum (-inspired) computing resources in a production context
- What tools are available?
- What are their strengths and weaknesses?
- Fixed timeouts

- Sherrington-Kirkpatrick
- Feature selection
- Traveling salesman
- Bin packing
- Pizza parlour (integer LP)

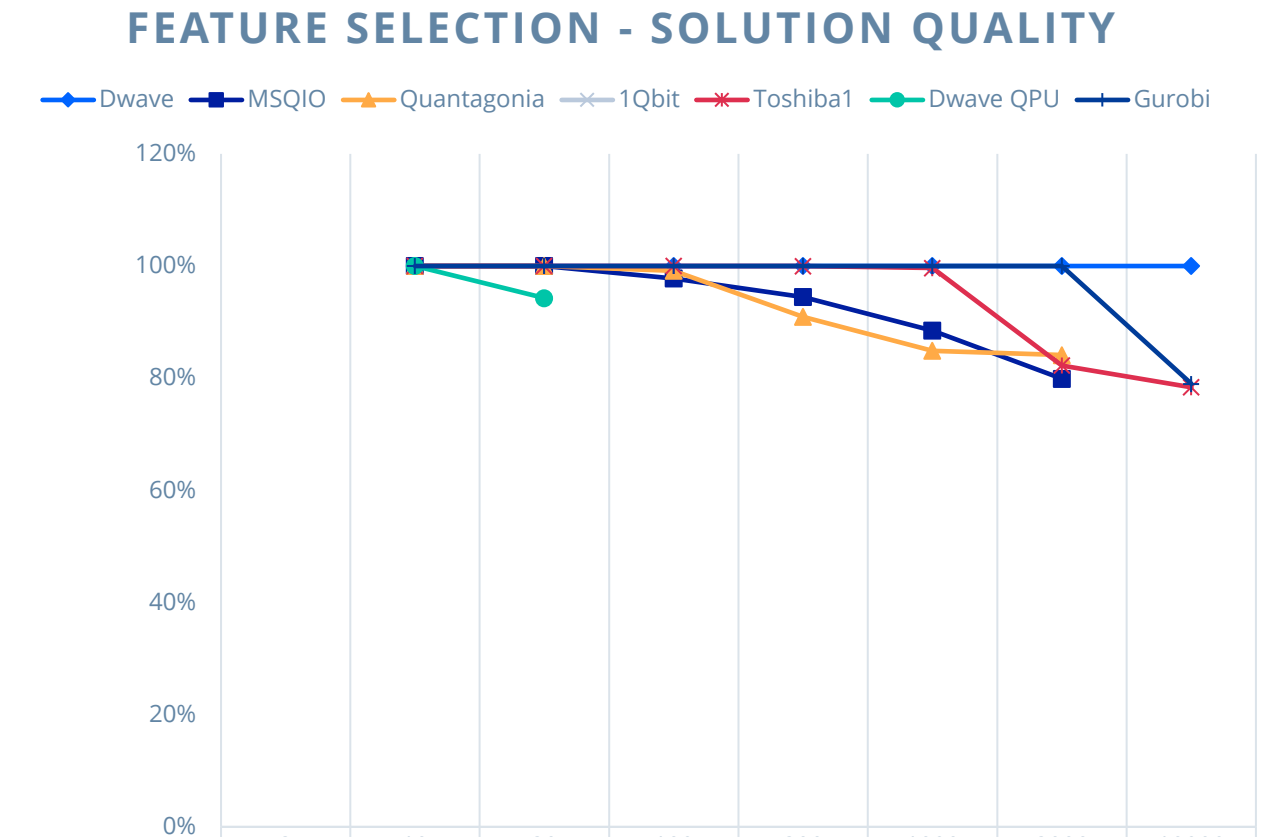
SK spin glass

- Perfect annealer use case
- Difference between D-Wave cloud service and QPU very significant
- Gurobi struggles a bit

	3	10	30	100	300	1000	3000	10000	30000	100000	300000	1000000
Dwave		100%	100%	100%	100%	100%	100%	100%				
MSQIO		100%	100%	100%	100%	100%	97%	91%				
Quantagonia		100%	100%	100%	99%	92%	93%					
1Qbit		100%	100%	100%	98%	96%						
Toshiba1		100%	100%	100%	100%	100%	100%	100%				
Dwave QPU		100%	100%	98%								
Gurobi		100%	100%	100%	99%	100%	97%	96%				

Feature selection

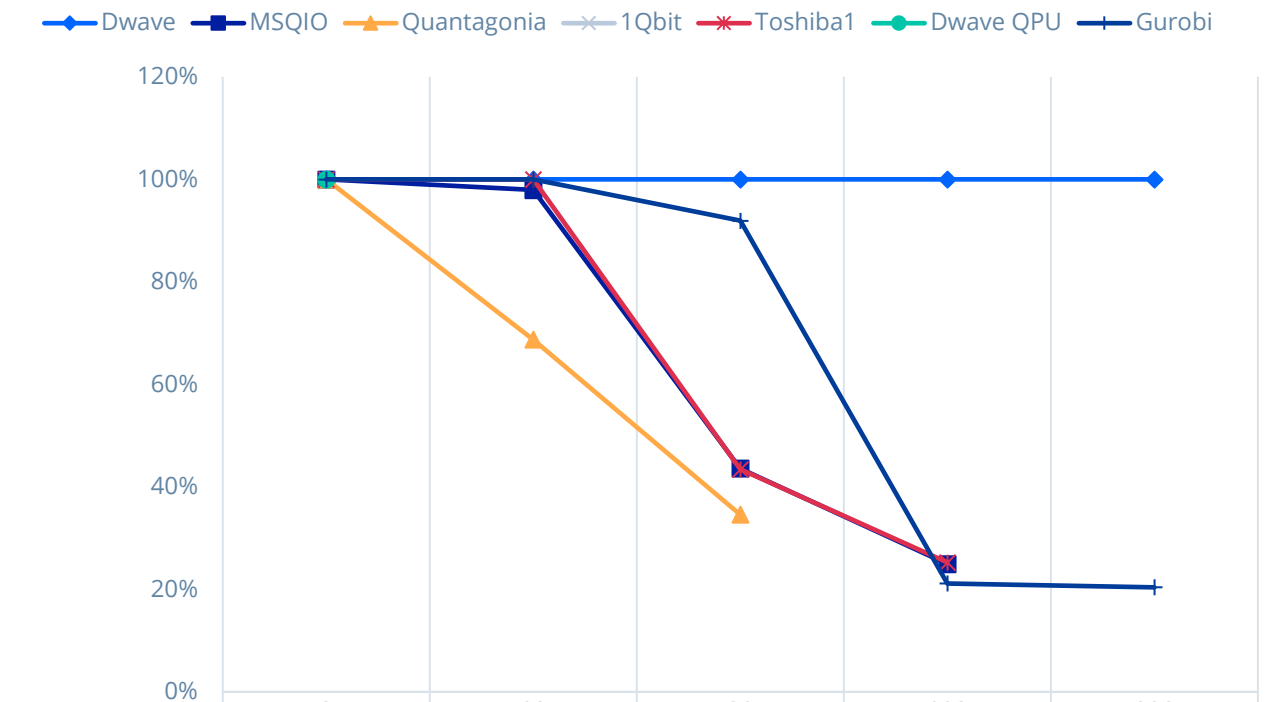
- Perfect annealer use case
- Similar to SK but includes a constraint (the number of features)
- Early application of quantum in the ML space



	3	10	30	100	300	1000	3000	10000
Dwave		100%	100%	100%	100%	100%	100%	100%
MSQIO		100%	100%	98%	94%	88%	80%	
Quantagonia		100%	100%	99%	91%	85%	84%	
1Qbit								
Toshiba1		100%	100%	100%	100%	100%	82%	78%
Dwave QPU		100%	94%					
Gurobi		100%	100%	100%	100%	100%	100%	79%

Traveling salesman

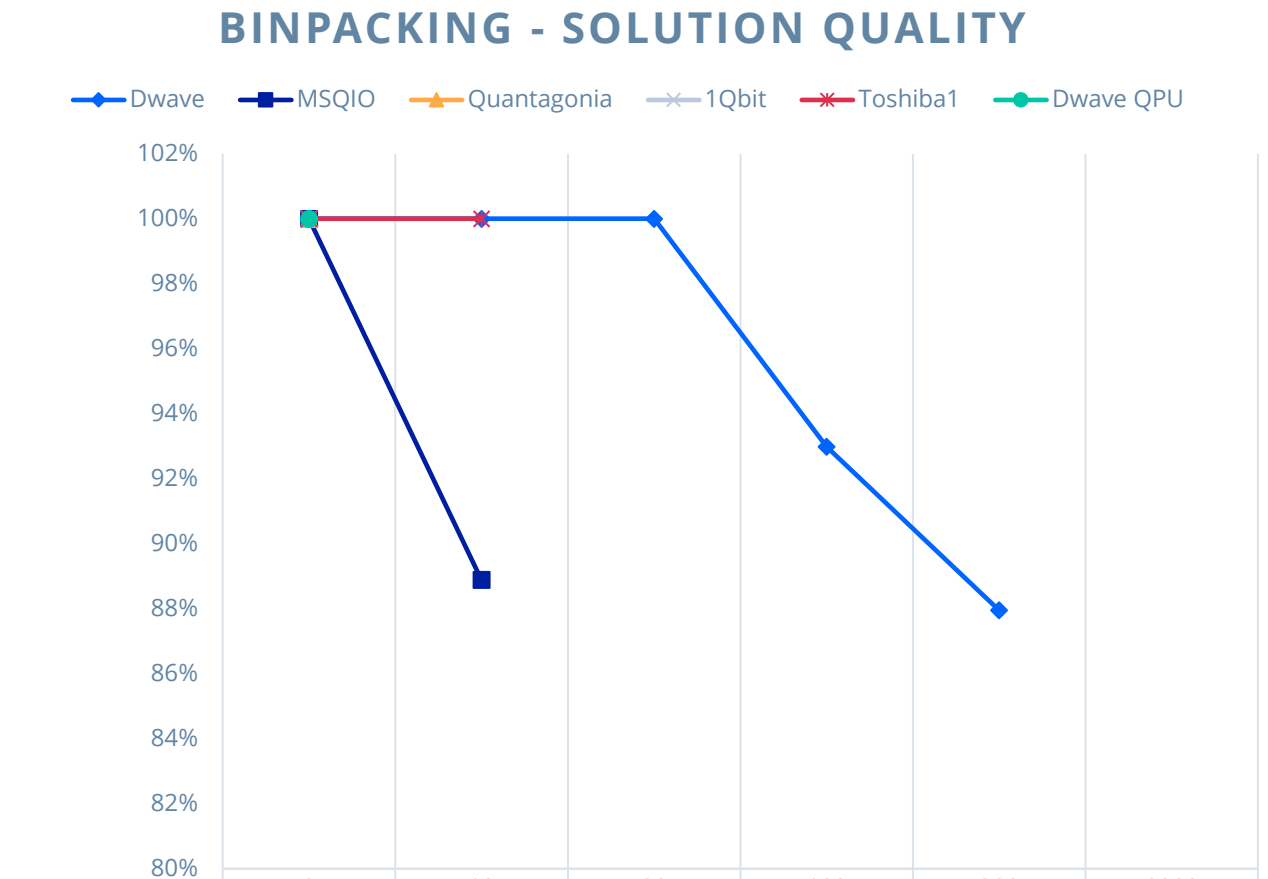
- Perfect annealer use case
- Representative of many business problems



	3	10	30	100	300
Dwave	100%	100%	100%	100%	100%
MSQIO	100%	98%	44%	25%	
Quantagonia	100%	69%	35%		
1Qbit					
Toshiba1	100%	100%	43%	25%	
Dwave QPU	100%				
Gurobi	100%	100%	92%	21%	20%

Bin packing

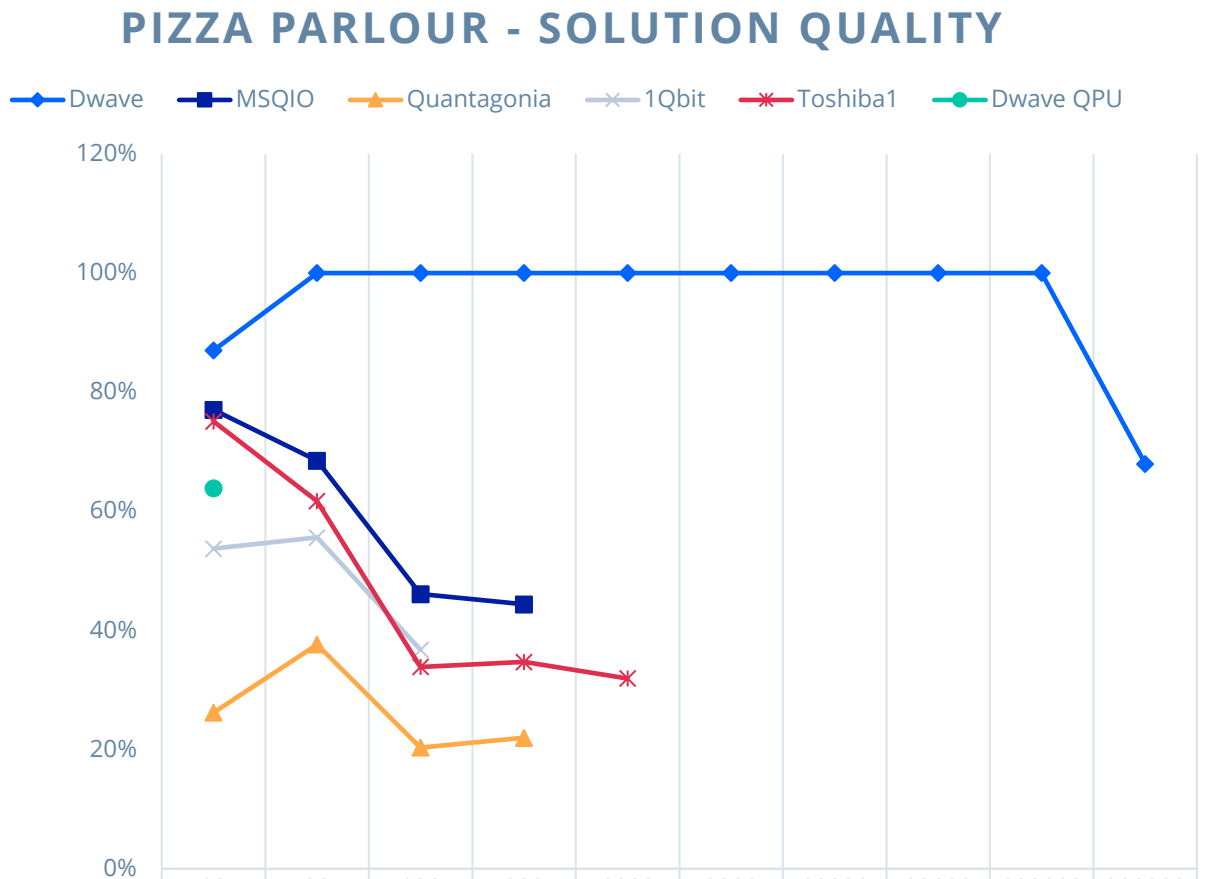
- Annealers really struggle
  - … but reformulation possible



	3	10	30	100	300	1000
Dwave	100%	100%	100%	93%	88%	
MSQIO	100%	89%				
Quantagonia	100%					
1Qbit	100%					
Toshiba1	100%	100%				
Dwave QPU	100%					

Pizza parlour

- Not annealer territory
  - … testing integer map
  - … annealers are more attractive with complex constraints or non-linear terms



	10	30	100	300	1000	3000	10000	30000	100000	300000
Dwave	87%	100%	100%	100%	100%	100%	100%	100%	100%	68%
MSQIO	77%	68%	46%	44%						
Quantagonia	26%	38%	20%	22%						
1Qbit	54%	56%	37%							
Toshiba1	75%	62%	34%	35%	32%					
Dwave QPU	64%									

4. Conclusion

The bottom line

Conclusion

The annealer landscape

- Quantum(-inspired) annealers can bring value
- D-Wave the only quantum show in town
  - … but mostly as quantum/classical hybrid
  - … the QPU more limited than quantum inspired options
- Hybrid needed for most business problems
- Toshiba the strongest after D-Wave

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Thank you for your attention

If you want to know more, please contact us

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Resources

- *Computational multiqubit tunnelling in programmable quantum annealers*, Boxio et al (2016), Nature Communications **7**, 10327 (https://www.nature.com/articles/ncomms10327, arXiv:1411.4036v2)
- *Reexamination of the evidence for entanglement in a quantum annealer*, Albash et al (2015), Physics Review A **92**, 062328 (https://journals.aps.org/pra/abstract/10.1103/PhysRevA.92.062328, arXiv:1411.4036v2)
- *Ising formulations of many NP problems*, Andrew Lucas, Frontiers of Physics **12** (https://arxiv.org/abs/1302.5843, arXiv:1302.5843)

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