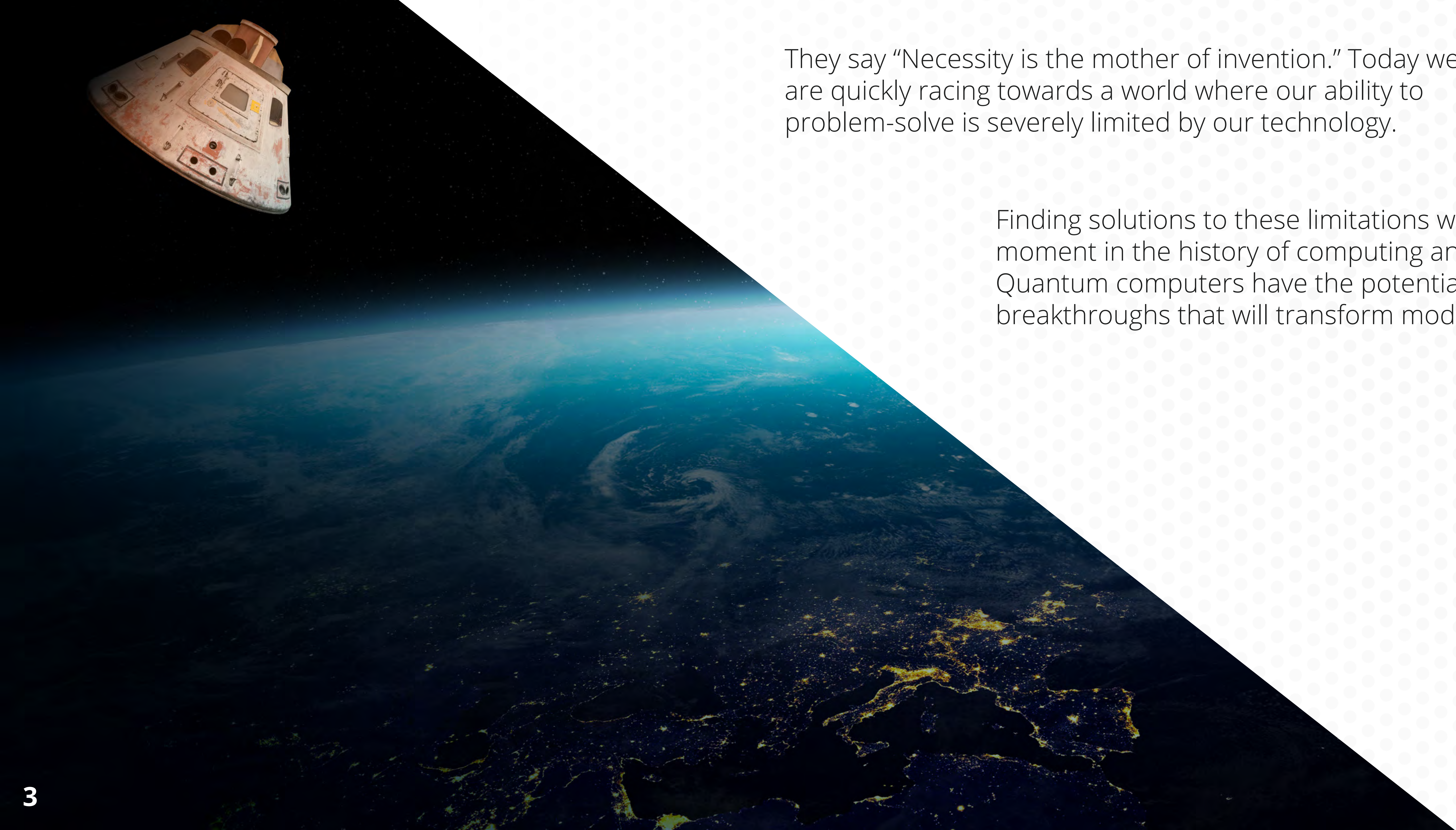
D-Wave

Solving For A Complex Future

UNLOCKING PRACTICAL QUANTUM COMPUTING

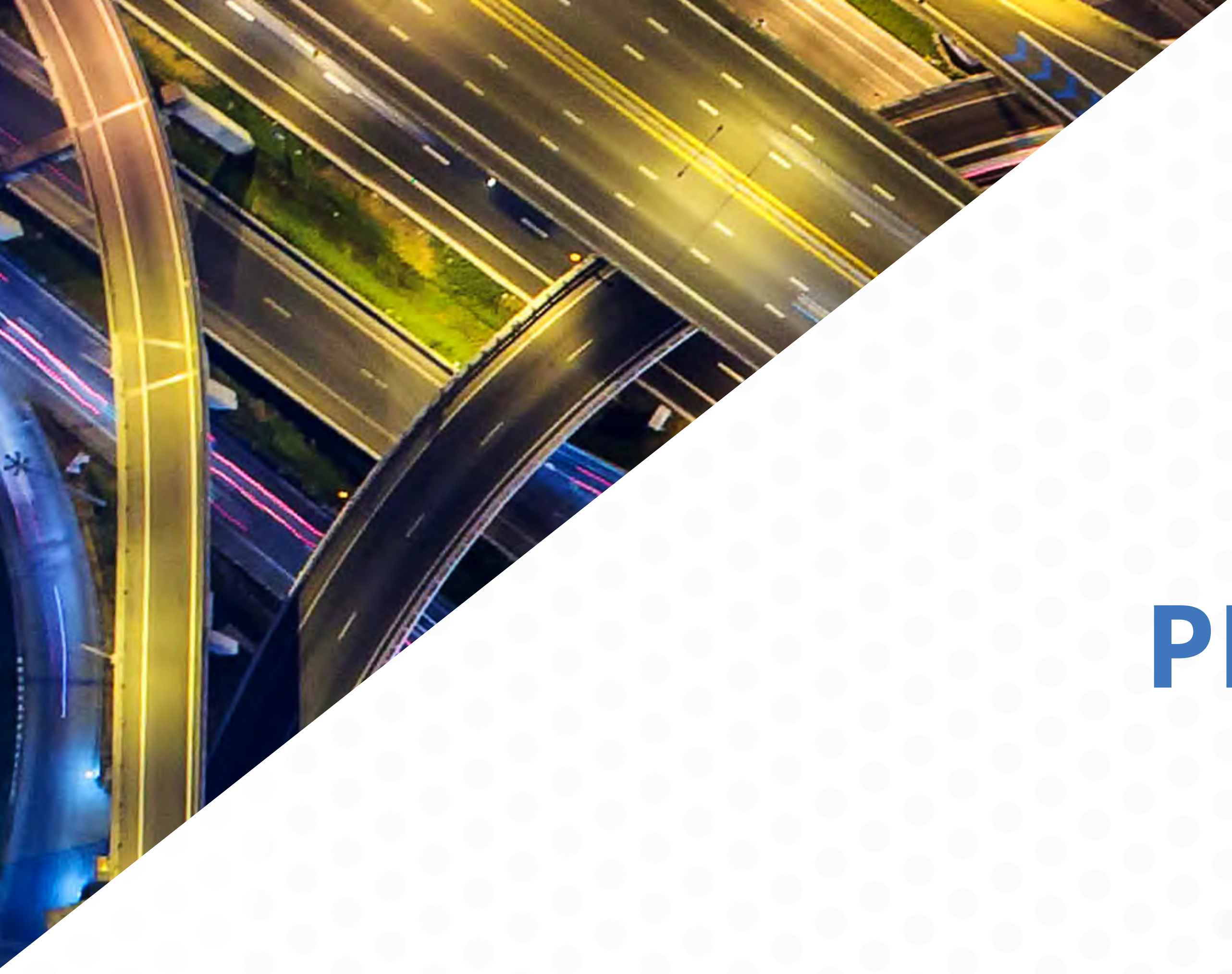


HOUSTON, WE HAVE A PROBLEM.

They say "Necessity is the mother of invention." Today we are quickly racing towards a world where our ability to problem-solve is severely limited by our technology.

Finding solutions to these limitations will reflect a watershed moment in the history of computing and usher in a new age. Quantum computers have the potential to facilitate extraordinary breakthroughs that will transform modern society.

We need to innovate.



PROBLEMS ARE GETTING MORE COMPLEX

Today's biggest problems are more complex than ever, with seemingly endless variables and wide-ranging impacts that can change the world we live in. In fact, these problems are so complex that classical computers can't keep up—either solutions take too long or, in many cases, they lack the computational power needed to solve the problem at all.

The growing investment and interest in quantum computing is driven by the potential that lives could be saved by more efficient and effective drug designs, that discovery in materials science could be revolutionized by simulations of quantum processes, and that the volumes of data we generate today could lead to powerful insights tomorrow.

WE NEED WAY MORE POWER

Growing power consumption and decreasing power availability dramatically escalate the power costs of today's supercomputers—typically in the millions of dollars each year—and tomorrow's exascale computers will cost even more. By comparison, the peak power draw of a D-Wave system is only 16 kW, resulting in an electricity cost of only $16,000 per year (assuming $0.10 per kWh).

D-Wave's quantum processing units (QPUs) show promise in significantly increasing the power efficiency of computing. In a recent study, the D-Wave 2000Q™ system was shown to be up to 100 times more energy efficient than highly specialized algorithms on state-of-the-art classical computing servers, when considering pure computation time, suggesting immediate relevance to large-scale energy-efficient computing.

TRADITIONAL COMPUTING IS SLOWING DOWN

Moore's law is showing its age. Traditional computing architectures are beginning to see diminishing returns from scaling up, as ever greater amounts of power are required for even minimal speed gains.

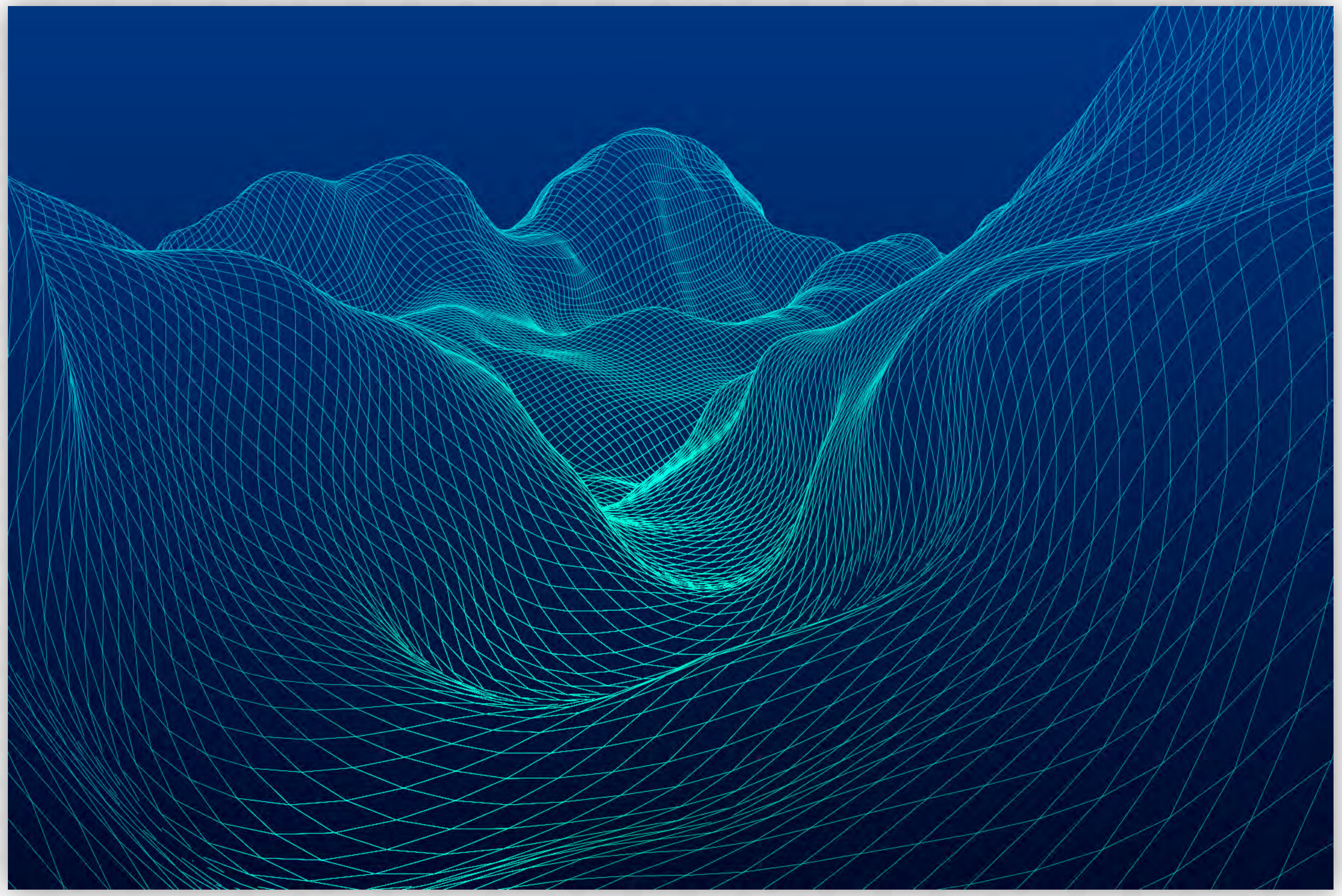
In 2011, a study in the journal *Science* showed that the rate of change of the world's capacity to compute information peaked in 1998. Since then, technological change has slowed, prompting a search for alternatives to traditional computing systems. D-Wave's quantum systems harness the power of quantum mechanics to deliver greater computing power not limited by classical architectures.

SO WHAT HAPPENS NOW?

We go quantum.

What is different about quantum computing?

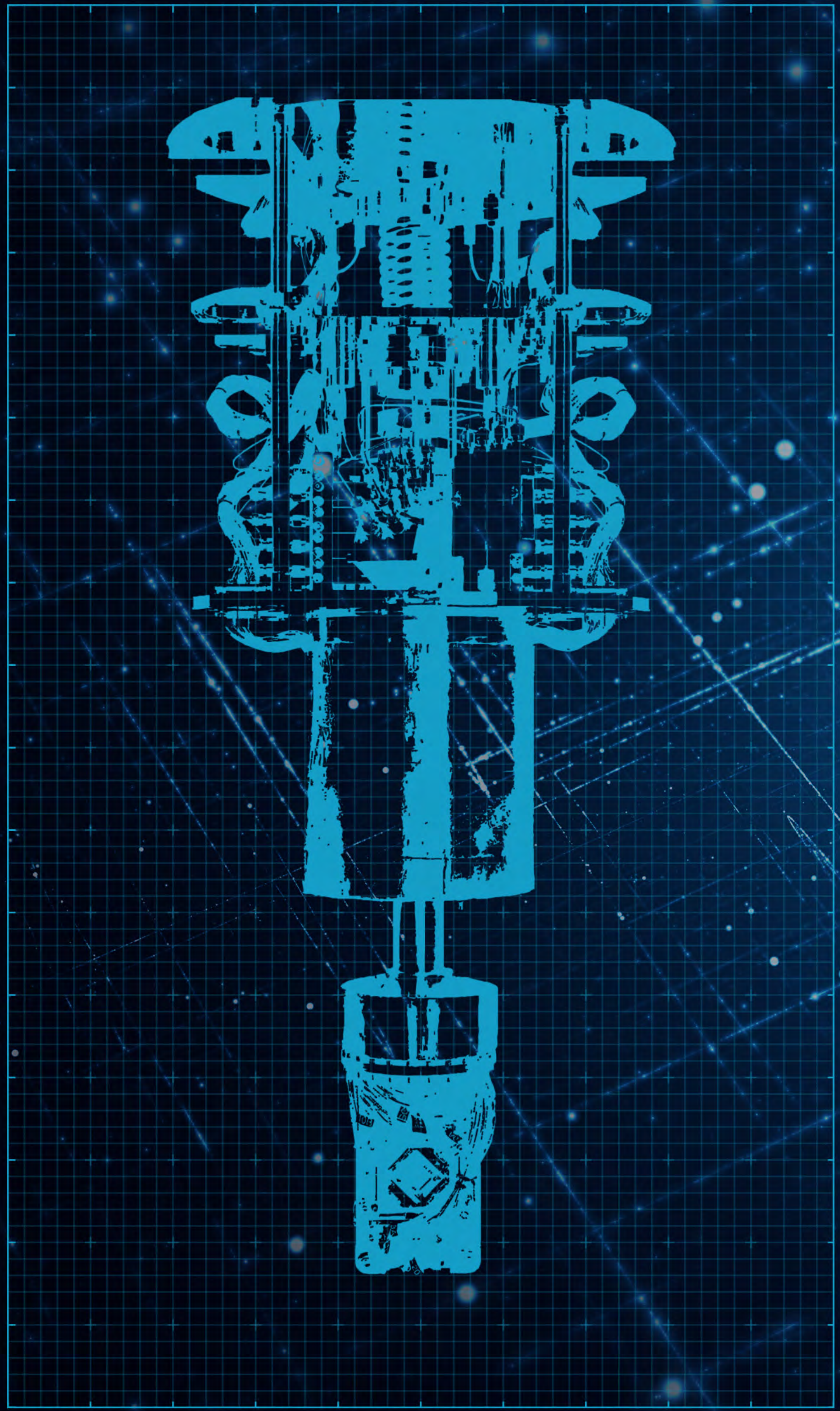
Solving a hard computational problem requires searching a space of possible solutions. This is like looking for the lowest point in an enormous and complex landscape, as shown here.



Classical computers use bits. A classical computer can represent one square at a time, and it solves problems by stepping from square to square in search of the lowest point.

Quantum computers use qubits. This gives a quantum computer powerful new capabilities for searching the space by exploiting quantum shortcuts: it can visit multiple valleys simultaneously, and it can tunnel through hills rather than climbing over.

These shortcuts give quantum computers the potential to solve some kinds of problems much faster than is possible with classical computers: think seconds instead of years of computation time.



Why is building a quantum computer hard?

Qubits are finicky and hard to control. Like Schrödinger's cat, the quantum computation must be protected against all forms of energy—called noise—from the surrounding environment. Too much noise and the computation fails: you get a wrong answer.

No real-world quantum computer can be completely protected from noise. If it fails, you can try again, but a too-high failure rate will cancel out any speedups found by exploiting those quantum shortcuts.

A quantum computer can only realize its enormous potential to outperform classical computers if:

- Qubit counts are large enough to solve interesting problems
- Error suppression is good enough for practical use

These are the two main technological challenges facing every organization in the race to make quantum computing a reality.

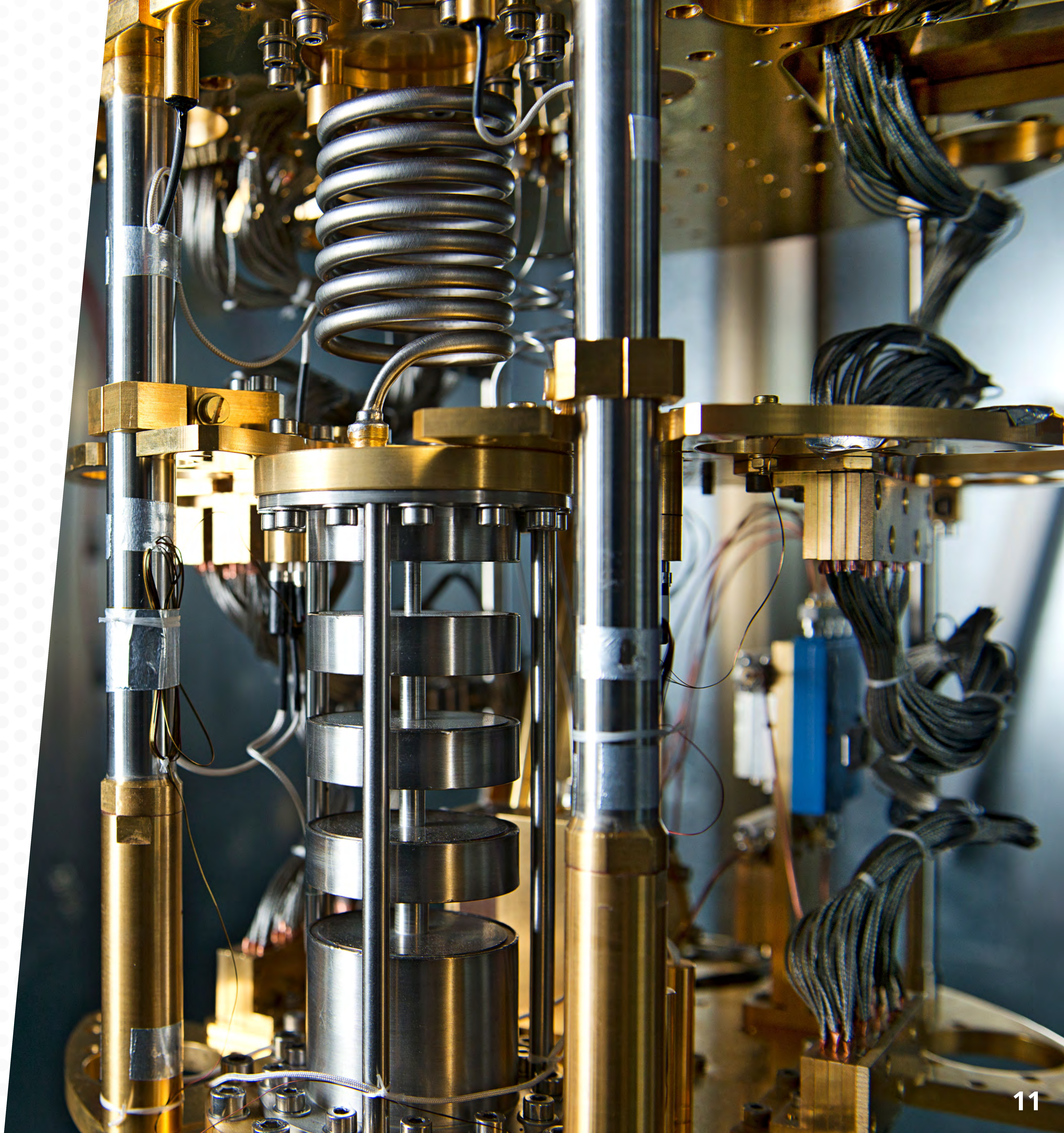
IS THIS EVEN POSSIBLE?

"We are an impossibility in an impossible universe."
-Ray Bradbury

Rise of the quantum annealer

The two main approaches to building quantum computers are quantum annealing (QA) and gate model (GM). Each supports different types of quantum shortcuts; each has its pros and cons.

One huge pro for QA is buildability: QA is fundamentally more robust against errors, so it is easier to build working quantum computers at industrially-relevant scales.



Part of the dilution refrigerator that cools the QPU

D-Wave stands out from the pack

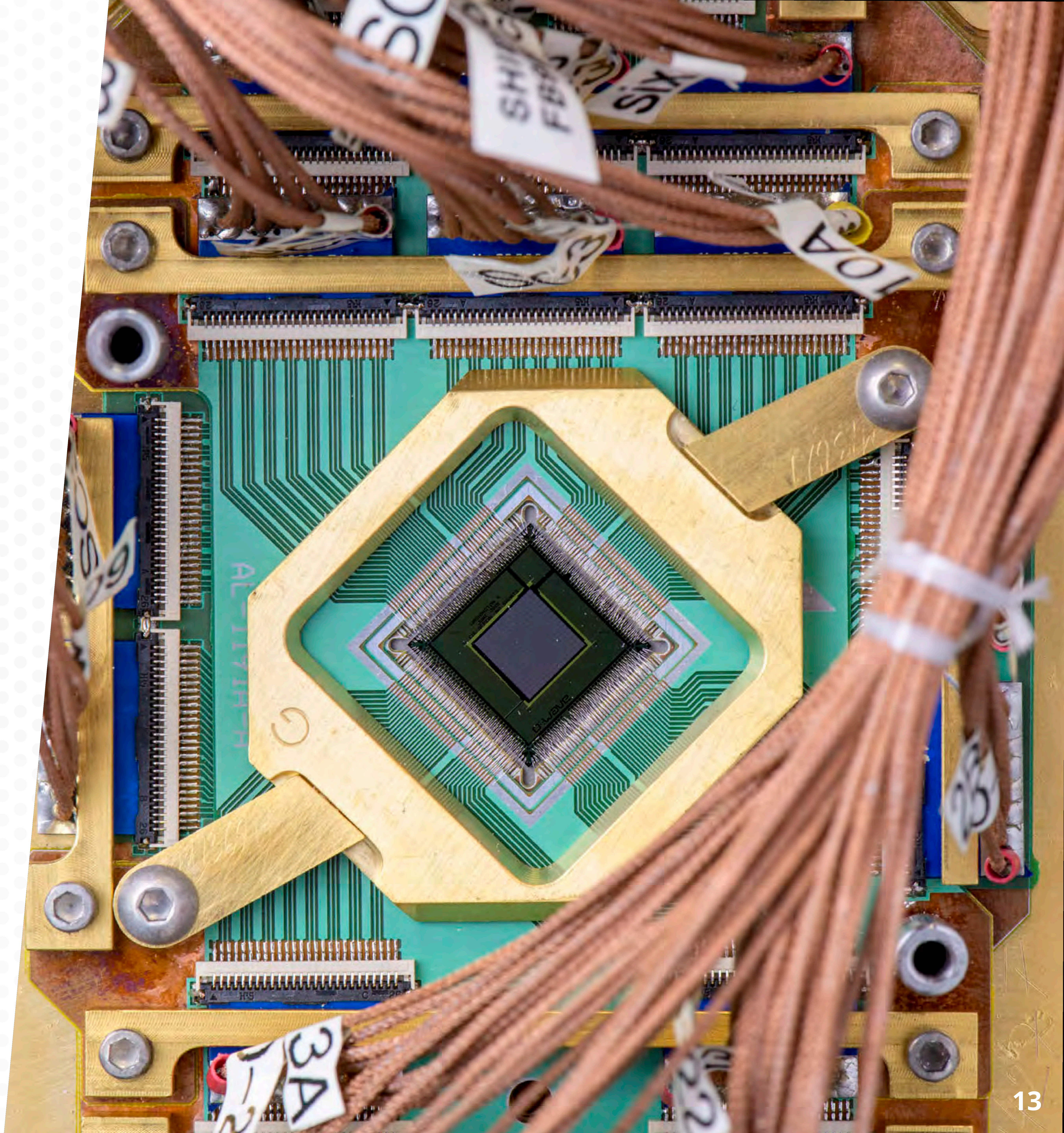
Big and small companies have thrown their hats into the quantum arena. But D-Wave stands out from the pack:

- D-Wave is the second largest patent holder in Canada, and the undisputed leader in QA-based quantum computing.
- Since 2008, D-Wave has been building working quantum computers and scaling up qubit counts at a pace matching Moore's law. Over the same period, error suppression has improved, and computation times have gotten faster.
- D-Wave is not slowing down: innovation is expected to continue for the foreseeable future.
- D-Wave is the first company to build and sell commercial quantum computers.

The quantum era begins

Many companies around the world, maybe including your competition, have started exploring ways to harness the potential of quantum computing.

More than 200 early applications, from a wide range of industries, have been implemented and run on D-Wave systems. All were made possible because D-Wave has solved many of the early engineering challenges, though more remain ahead.



A 2000-qubit QPU


SCIENCE
DEFENSE
AEROSPACE
MEDICINE
D:wave
Unlocking practical
quantum computing
TRANSPORTATION
COMMUNICATION
ANALYTICS
LOGISTICS
E-COMMERCE

CASE STUDY: TRANSPORTATION

Volkswagen

Volkswagen: Addressing the complex problem of traffic congestion

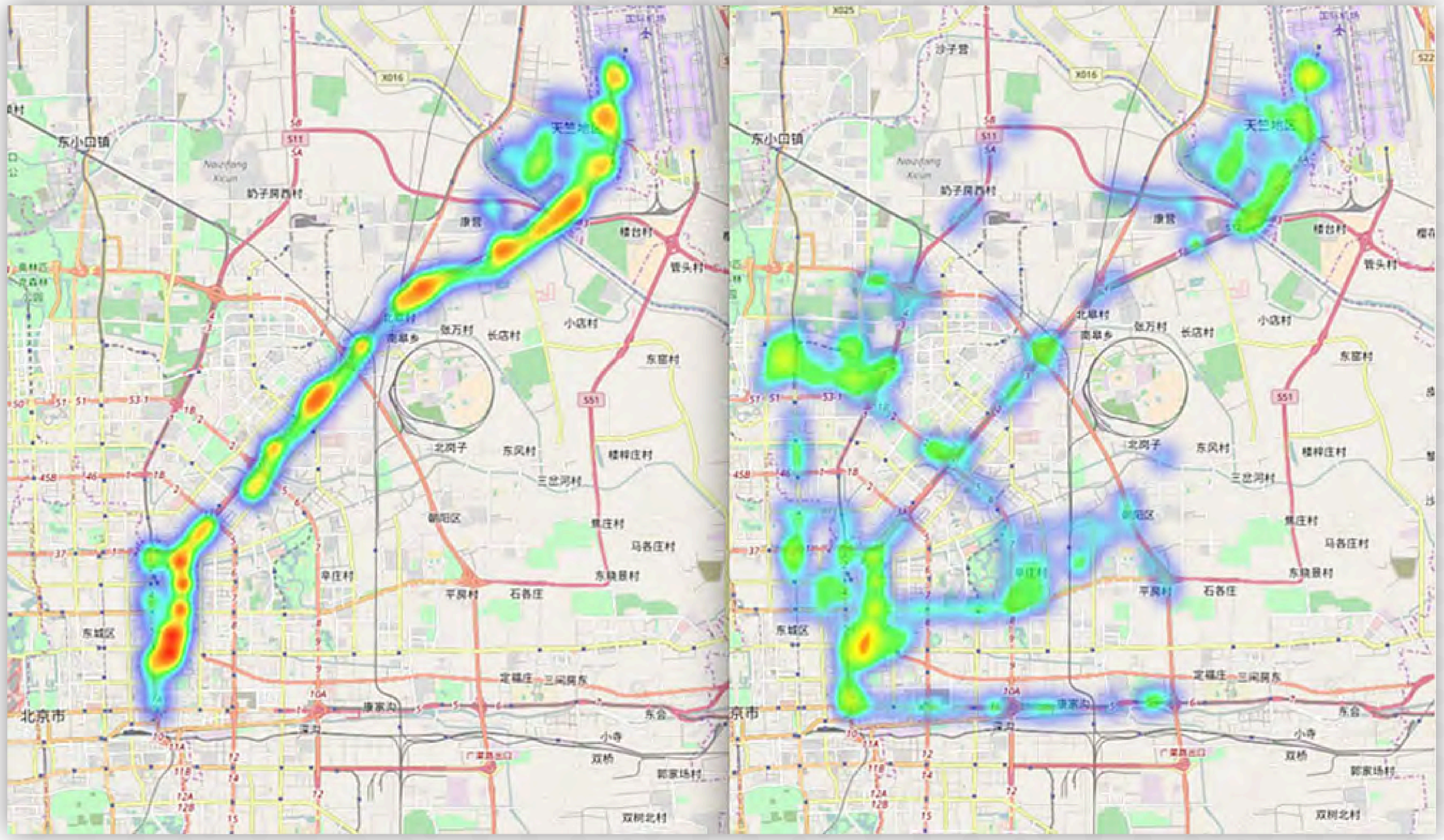
D:WAVE

Traffic-flow Optimization

Using movement data collected from 418 taxi cabs in one of the busiest cities in the world—Beijing—the team sought to optimize traffic flow between the city center and the Beijing airport. Based on the proof-of-concept, Volkswagen developed a mobile app to optimize bus routes and unveiled it to attendees of the 2019 WebSummit in Lisbon. This was the first production version of a quantum application!

"What makes the now developed solution so special is the possibility to scale it to any city. Size, infrastructure, traffic volume—quantum computers enable us to adapt our solution to all conceivable conditions."

- Principal Scientist at Volkswagen's CODE Lab in San Francisco



Result: unoptimized vs. optimized traffic


Menten AI
Menten AI: Reimagining Biology with Quantum-Powered Protein Design
D:wave

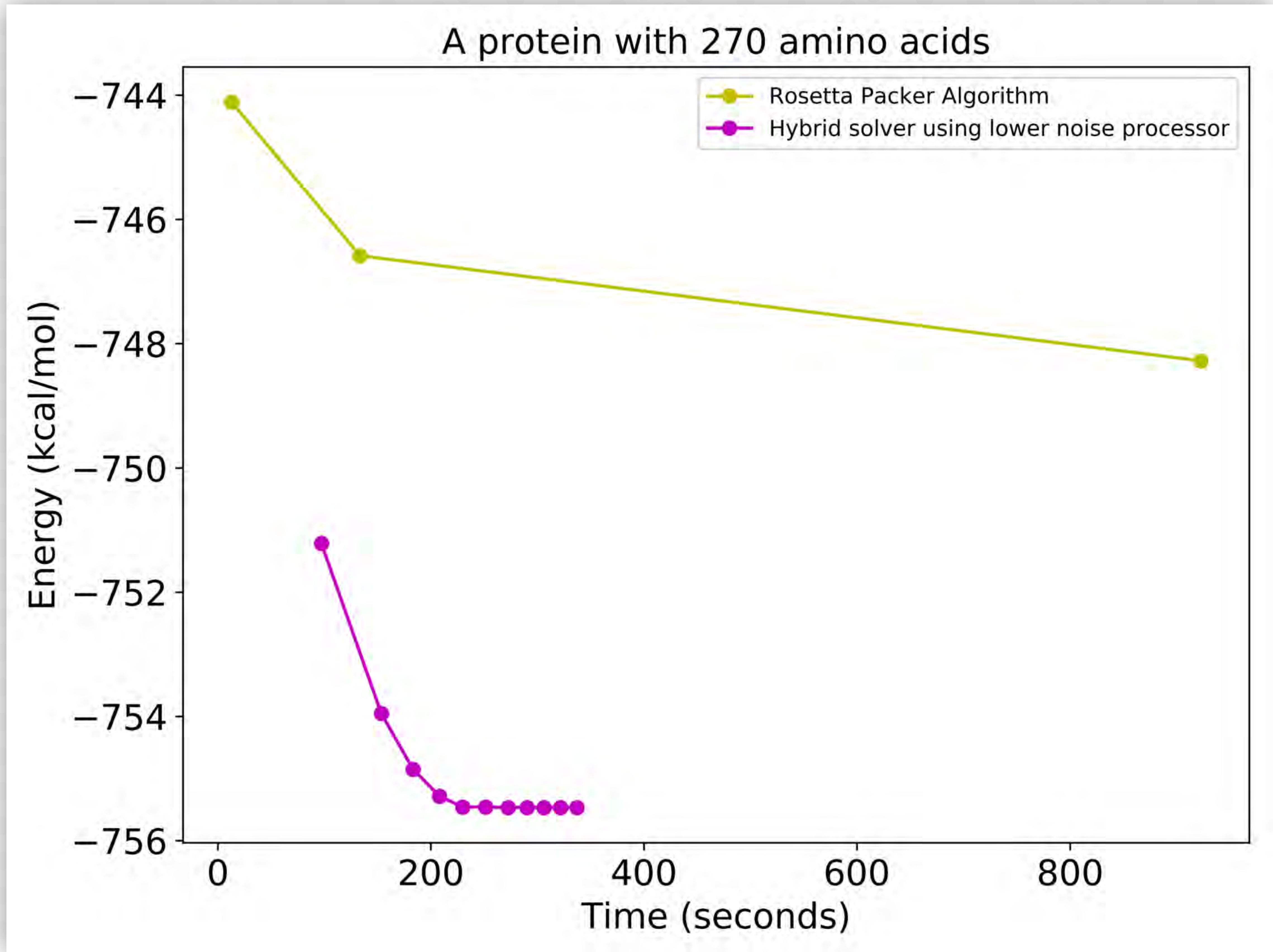
Quantum Protein Design

Designing and modifying proteins is widely applicable to drug development and targeted disease therapeutics. Creating these proteins, however, is complex, time-intensive, and resource-heavy work.

Using a hybrid quantum-classical approach, Menten AI sought to reduce the cost and time required, as well as overcome the scalability challenges that limit classical approaches. With D-Wave's hybrid solver, Menten AI has already achieved better solutions, faster.

"Using D-Wave's hybrid quantum-classical technology helps us to solve much larger problems in a fast and efficient manner, and allows us to not only design these molecules today, but also reimagine tomorrow's therapeutics."

- Dr. Vikram Mulligan, Flatiron Institute Research Scientist and Co-founder of Menten AI



Recruit Communications: Leveraging D-Wave to improve e-commerce hotel listing sales

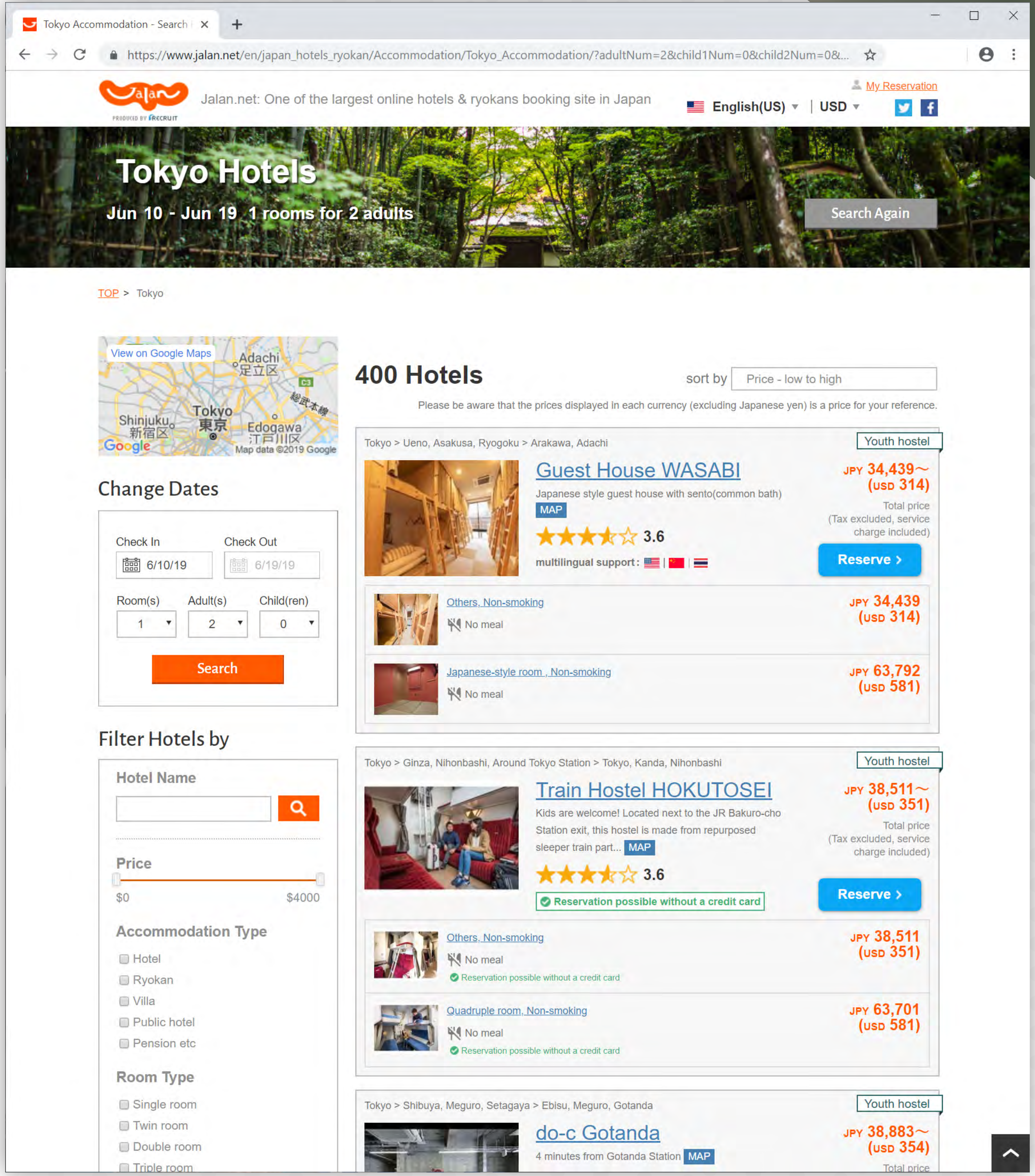
Next-Level E-Commerce

For their hotel reservation website, lists are created every day based on an algorithm designed to maximize sales. Recruit researchers set out to improve the algorithm.

The prototype's goal was to rank items with high sales potential in higher positions on the list, making it easier to find popular items. The new algorithm also emphasizes diversity in the items in high ranked positions to make customers aware that they have a wide range of options.

"Solving the problem considering diversity with D-Wave, we got an item list reflecting both scores and diversity at least +1% sales uplift"

- Kotaro Tanahashi of Recruit Communications



QxBranch: Predicting election outcomes

Predicting Elections: Finding the Flaws

News > World > Americas

Survey finds Hillary Clinton has 'more than 99% chance' of winning election over Donald Trump

The Princeton Election Consortium found Ms Clinton has a projected 312 electoral votes across the country and only 270 are needed to win

Rachael Revesz New York | @RachaelRevesz |
Saturday 5 November 2016 17:44 | 99 comments

"The QC-trained networks gave Trump a much higher likelihood of victory overall, even though the state's first-order moments remained unchanged." - *QxBranch*

Where did the models go wrong?

Models failed to capture the correlation between U.S. states.

Most models assumed each state was independent from other states.

Models using correlations can capture higher-level, richer structure in the data.

With quantum machine learning, the QC-trained networks were able to learn structure in polling data to make election forecasts in-line with the models from award-winning opinion pollsters, fivethirtyeight.com.

Additionally, the QC-trained networks gave Trump a much higher likelihood of victory overall, even though the state's first-order moments remained unchanged.

In addition, the QC-trained network learned quickly, and since each measurement is a simulation, each iteration of the training model produced 25,000 simulations (one for each national error model). This eclipsed the 20,000 simulations fivethirtyeight.com performed as they reran their models.

ARE YOU READY FOR QUANTUM?

For every Yes answer, award yourself the number of points shown in parentheses.

1. Is the core problem NP-Hard? If so:

Is it a decision problem (**3**)?

Is it a constraint satisfaction problem (**3**)?

Is it an unconstrained discrete optimization problem (**5**)?

If it is a constrained optimization problem, are the constraints local (**4**), or global (**2**)?

Does the problem require samples of solutions as opposed to just one solution (**3**)?

2. In what form is your output?

Binary variables (**5**)?

Binary strings (**5**)?

Elements of a small-domain set such as {A,C,G,T} (**3**)?

3. Assuming your inputs can be represented by graphs, how big are the graphs?

Do they have fewer than 100 nodes (**5**)?

Are they sparse with fewer than 1000 nodes (**4**)?

If larger, would it be viable to decompose the graphs into parts that can be solved separately (**3**)?
D-Wave can provide the decomposition code.

4. How much time does your current solution method take to return satisfactory results?

More than half a second (**5**)?

More than 10 seconds (**5**)?

If your score is above 12, you may have a good candidate for a quantum solution. If not, maybe next year. Continue to follow D-Wave as we grow our platforms and widen their range of applicability.

The best way to predict the future is to invent it.

- Alan Kay

D-Wave Leap

200+ User-developed early quantum applications on D-Wave

Build and deploy quantum applications with Leap, the quantum cloud service.

Leap provides:

- **Cloud access to D-Wave quantum computers**
- **Hybrid solver service to easily solve large and complex problems**
- **Integrated Developer Environment with code examples, demos, Ocean SDK, visualizer, and more**
- **Interactive online community**

TAKE THE LEAP

You can do this!

If you can read a simple Python program, you can follow the code demonstration and try giving the live quantum computer problems to solve

If you can't read code, no worries: Leap has demonstrations to give you a basic idea of how it all works.

Leap also has tools for those new to quantum computers, and for experienced quantum application developers.

Get Started Today!

The probabilities are endless™