Microsoft

Quantum impact: **Transportation and logistics**

http://microsoft.com/quantum

Quantum impact: Transportation and logistics

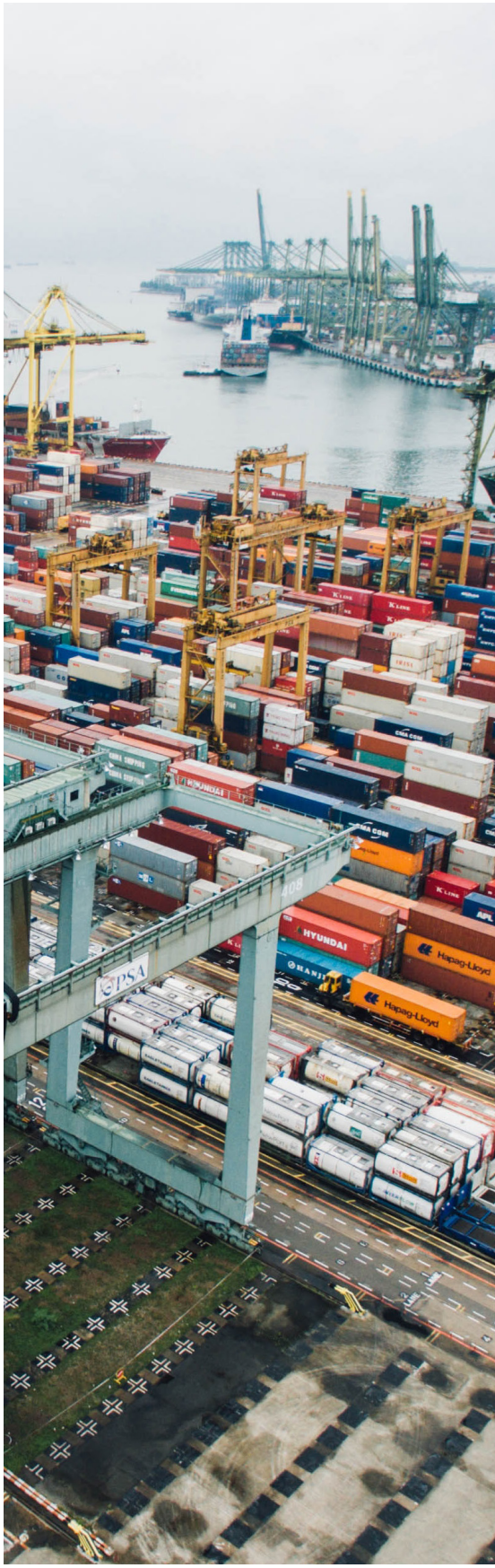
By viewing problems of transportation and logistics through a quantum lens, we see a profound impact on how goods, services, and people move through cities and the around the world.

Imagine entire cities where movement—motor vehicles, bicycles, scooters, pedestrians—is routed in the safest, most efficient ways in real time; where ride-shares, taxis and buses do not run on fixed schedules or routes but are sent to where anticipated demand will be greatest.

Or a global logistics system with parts, products and people arriving at the right places at the right times, with the most efficient way of assembling and moving goods and services with the least resistance.

Many real-world optimization problems remain unsolvable despite the remarkable advancement in both algorithms and computing power over the past decades. In addition, because of the difficulty of simulating the characteristics of complex molecules, the development of new materials with specific properties—like next-gen batteries—poses huge computational challenges as well.

And with quantum breakthroughs in material science, lower emissions and better efficiencies begin to come into focus.



The promise of quantum

Quantum computing makes use of wave-like properties of nature to encode information in qubits that can process highly complex calculations more quickly. Where current computers would require billions of years to solve the world's most challenging problems, with the right algorithm, a scaled quantum computer could find a solution in weeks, days, or hours.

When designed to scale, quantum systems will have capabilities that exceed our most powerful supercomputers. As the global community of quantum researchers, scientists, engineers, and business leaders continue to collaborate to advance the quantum ecosystem, we expect to see quantum impact accelerate across every industry.

From bits to qubits

The quantum bit, or qubit, is the basic unit of quantum information. Whereas a classical bit holds a single binary value, 0 or 1, a qubit can be in a "superposition" of both values at the same time. This enables quantum mechanical effects such as interference, tunneling, and entanglement, which in turn empower quantum algorithms for faster searching, better optimization, and greater security. When multiple qubits are connected, these properties can deliver significantly more processing power than the same number of classical bits. For instance, four bits is enough for a classical computer to represent any number between 0 and 15. But four qubits is enough for a quantum computer to represent every number between 0 and 15 at the same time.

Quantum-inspired solutions

Emulating these quantum effects on classical computers has led to the development of new types of quantum solutions that run on classical hardware, also called quantum-inspired algorithms.[1] These algorithms allow us to exploit some of the advantages of quantum computing approaches today on classical hardware, providing a speedup over traditional approaches. Using quantum solutions on classical hardware also prepares us for the future of quantum optimization on actual quantum hardware.

Traffic optimization

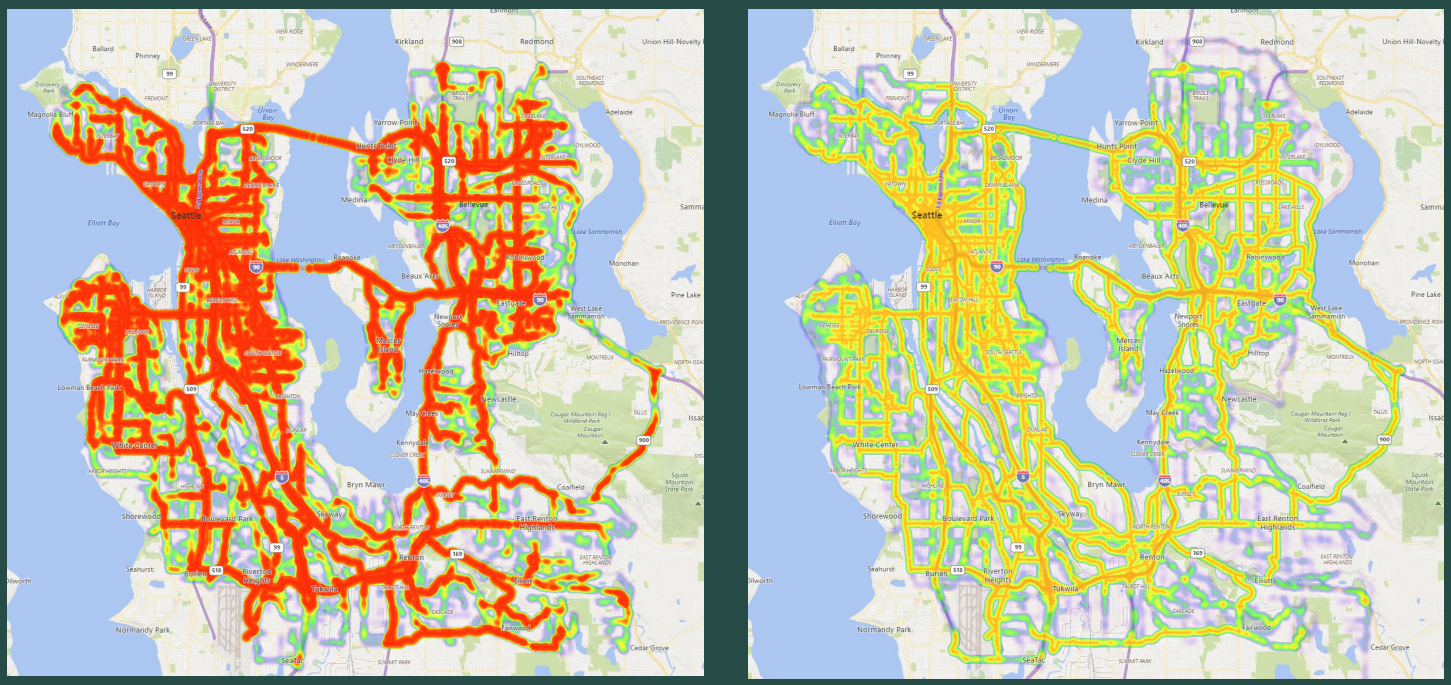
When you turn on your preferred navigation app in order to get the optimal route for where you're going, you're likely to get the same directions as everyone else in the neighborhood—and surrounding neighborhoods—is getting. These routes are based on the most recent, but not necessarily real-time, data. The fact that you are driving out of the neighborhood (along with your neighbors) means that you are actually changing the traffic in the area since there is a lag time between the traffic that accumulates before your GPS will re-route you.

With quantum-inspired methods, we can devise algorithms that takes this into account and optimize traffic in and out of areas, thus dramatically reducing the overall traffic at a citywide level.

When used at scale, optimized route guidance minimizes time idling in traffic, reducing fuel consumption and carbon emissions. Safety would be improved by managing traffic to avoid areas of large pedestrian and bicycle usage, or limit traffic in areas of poor visibility.

Beyond individual drivers, city planners could use such tools to model the impact of major infrastructure projects such as public transportation and road construction, or even critical scenarios like evacuation planning.

Case study:
Reducing traffic congestion



Traffic congestion results in a significant time and cost burden in many metropolitan areas. Another important use case for vehicle routing is the efficient evacuation of large urban areas.

Using quantum-inspired methods paired with a sophisticated mathematical representation of the problem, Ford and Microsoft worked together[2] to significantly reduce both congestion and travel time versus the routing recommendations from Bing Maps.

Preliminary studies with up to 5,000 vehicles show more than a 70% decrease in congestion, as well as a reduction of average travel time of approximately 8% (compared to the best routes provided by Bing Maps).

The image above shows travel patterns for 5,000 vehicles around the Seattle metropolitan area at rush hour. The quantum-inspired algorithm-optimized routes, represented by a heatmap (right panel) show less congestion than the Bing Maps suggestions (left panel).

While traffic optimizations of approximately 400 vehicles takes 20 seconds on a quantum annealing machine[3], our quantum-inspired algorithms tackle a comparable problem in only 0.02 seconds on a single CPU core. This can be further accelerated using specialized hardware, such as FPGAs available in Azure, by at least two orders of magnitude, which enables the speed required to address the scale of real-world routing complexity, well beyond simple toy problems.

Fleet management

A very simple example of fleet management is around routing and scheduling deliveries. Let's say there is a warehouse of items, each of which goes to a specific address. The problem of scheduling drop-off and installation for a variety of units, each with its own weight, size, delivery window, and so on, increases exponentially with each additional constraint.

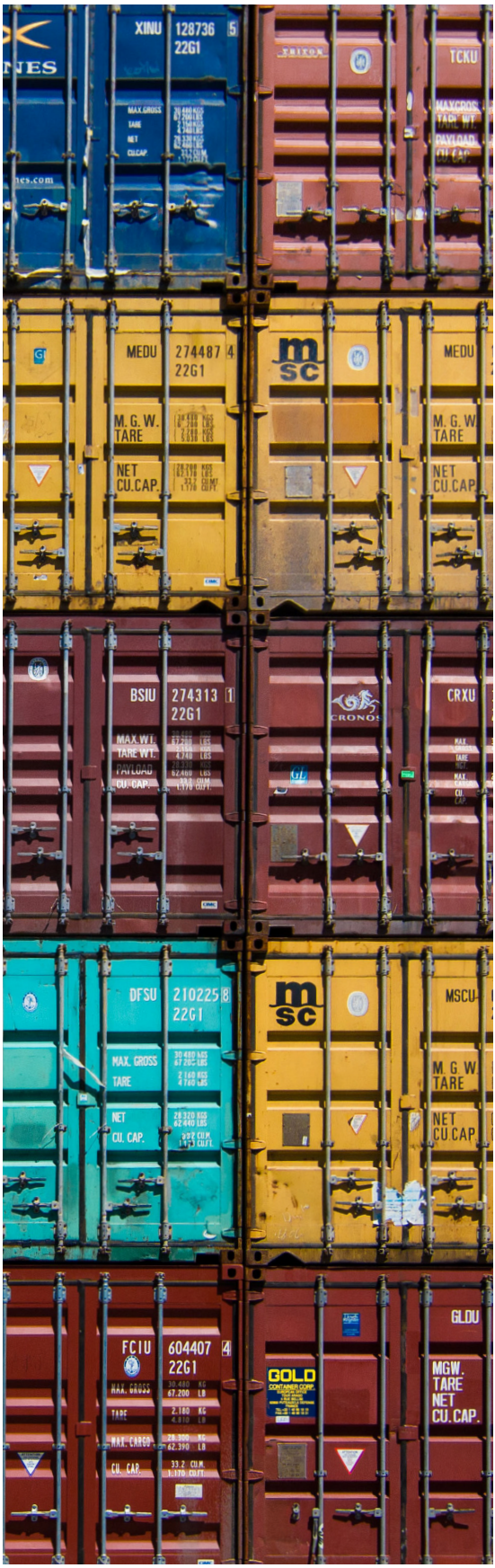
Companies want to optimize usage of resources, such as distance travelled or idle time, and while classical computing gives us algorithms that can handily minimize or maximize some values, quantum computing gives us the ability to makes the biggest impact with these complex ecosystems.

In the example above, the "system" is still quite simple. By adding factors to the ecosystem (traffic, road closures, return time to depot, etc.) it becomes exponentially complex and extremely difficult to optimize.

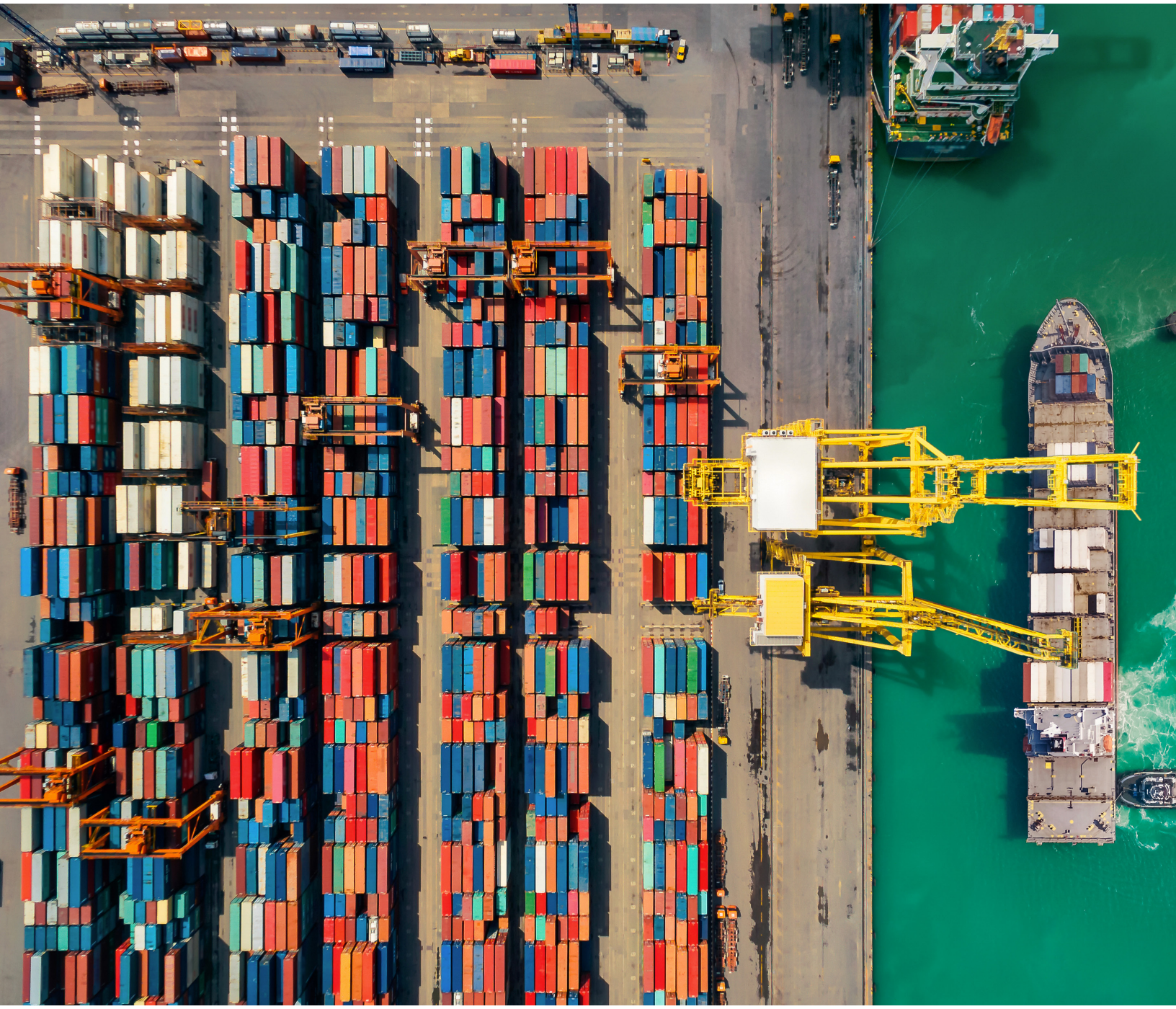
For example, consider scheduling ten delivery trucks, each taking one of four possible routes between its pickup and delivery locations; that is 4^{10} (1,048,576) options, which a classical computer can handle pretty easily. But what if there were 30 trucks over these four routes? There 4^{30}—over a quintillion—options, with just two factors: number of trucks and number of routes.

With quantum, we can calculate better scenarios because of quantum computing's ability to tunnel through infeasible options, we can calculate better scenarios, faster than traditional annealing methods allow. And because of the rapidly changing sets of data used to calculate these ever-changing sequences of events (e.g. traffic, a technician calling in sick), even if the calculations were possible, the decisions based on a classical solution may be obsolete by the time the computations are complete.

Multiply this out to the most complex scenarios on a global scale, with multiple modes of transport—air, sea, ground—and we find that the process of scheduling and managing an entire transportation ecosystem is not possible with today's computing methods. Ships, trains, planes and trucks are generally scheduled independently because, as demonstrated above, the sheer number of variables make calculations impossible to solve as a system.



But these types of optimization problems are especially suited to quantum computing and today, we're using quantum-inspired methods in Azure in order to prepare for a time when quantum computing becomes widely available, providing opportunities for businesses to maximize efficiencies at a scope previously unimaginable.



Supply chain optimization

Just as with fleet management, supply chain optimization is well-suited for quantum. In today's global economy, with dependencies on suppliers from all over the world, optimizing resources, both material and human, is crucial for efficient operations. And with quantum-inspired methods to model many factors at once and provide estimated probabilities, organizations are able to better schedule their operations for peak performance.

Inventory optimization: Homing in on proper inventory levels, so there are no shortages or need for storage, ensures optimal manufacturing and cash flow.

Supply chain disruptions: With fast quantum algorithms, options for effective re-routing and re-planning may be calculated in the event of a disruption to the supply chain.

Logistics: Scheduling human resources and optimizing according to incoming and outgoing materials—along with accounting for variables and adjusting on the fly—can help make operations run more efficiently.

Risk management: By simulating different scenarios (e.g. capital allocation, disaster preparedness), probability outcomes may provide prescriptive direction to reduce risk.

Travel

Because of the ability of quantum to more efficiently explore thousands of scenarios, it may be applied to some of the most complex air and rail transportation problems.

Route and timetable scheduling

Quantum methods are able find routes for travelers via rail or air, including ground-air coordination, ultimately reducing cost and time spent in-transit. In addition, airlines and railway companies may find they are able to build daily ad-hoc routes to efficiently transport passengers to where they need to go, using their fleet most efficiently. And, with the ability to improve scheduling, the industry can better coordinate flights and trains to ensure on-time departures and arrivals with minimal wait time, reduce fuel consumption, and serve their customers more effectively—ultimately increasing profits.

Air traffic control

Quantum-inspired methods may also be used to more accurately model airline traffic, making the skies safer to fly. Airplanes will be able provide additional data to air-traffic control from both ground and air, simulating a myriad of scenarios, in order to find optimal flight paths and anticipate possible scenarios that may lead to failure. These "air-traffic control scenarios" are also being applied to transportation models within cities to coordinate traffic between cars, bikes, e-scooters and pedestrians in order to optimize multiple traffic scenarios.

Operations

Assigning gates, staffing crew, baggage handling, ground control, and parking are all operations can be better served by quantum-inspired optimization methods. Instead of each service working independently, all resources can be better coordinated, ensuring that both human and material resources are in the right place at the right time.

Case study:

Accelerating OLED design

OTI Lumionics has developed a fast materials design approach, tailored to OLEDs and other electronic materials.[4] They work with the largest electronics companies in the world to design new materials that are mass-production ready, enabling the next generation of consumer electronics.

OTI Lumionics has developed software tools to simulate and predict the properties of new materials, allowing a larger pool of candidates to be screened than could otherwise be experimentally synthesized and tested in the lab. Thus, new materials that meet the precise requirements of the largest electronics manufacturers can be "designed" rather than discovered by chance.

OTI Lumionics has been investigating new approximation techniques using quantum-inspired methods to help accelerate computational chemistry simulations of new materials. As quantum-inspired algorithms run on classical hardware, they can test this enhanced workflow for material discovery today.

With their algorithms now running on Azure Quantum, OTI Lumionics is able to demonstrate meaningful results on problems of commercially relevant size, today. For example, by using Azure Quantum's optimization tools in their pipeline, OTI Lumionics successfully performed a complete active space configuration interaction simulation of an archetype green light emitting OLED material—Alq3 [Tris (8-hydroxyquinolinato) aluminum].

Mapping the Alq3 simulation problem to an industry-standard quadratic unconstrained binary optimization (QUBO) problem would result 58,265 variables. Solving a QUBO problem with this many variables is intractable for both classical optimization methods and quantum annealers. In contrast, using Azure Quantum, the higher-order binary problem can be handled natively, meaning that this problem only requires 132 variables on classical hardware to perform the simulation.

Azure Quantum

Quantum computing applies the properties of quantum physics to process information. Where current computers would require billions of years to solve some of the world's most challenging problems, a scaled quantum computer may find a solution in weeks, days, or hours. Azure Quantum is an open ecosystem of quantum partners and technologies. Building on decades of quantum research and scalable enterprise cloud offerings, it is a complete solution that gives you the freedom to create your own path to scalable quantum computing.

Azure Quantum is also your entry point to integrate quantum inspired optimization running on classical Azure hardware for immediate results. Through a familiar Azure environment, you'll have access to all the tools and resources you need to quickly ramp up on your journey to a quantum future and have an impact with quantum technology today.

An open ecosystem, enabling you to access diverse quantum software, hardware, and solutions from Microsoft and our partners.

A trusted, scalable, and secure platform that will continue to adapt to our rapidly evolving quantum future.

Quantum impact today, with pre-built solutions that run on classical and accelerated compute resources (also referred to as optimization solutions).

Get ready for your Azure Quantum experience with the Quantum Development Kit

The Quantum development kit is an open-source development kit to develop quantum applications and solve optimization problems. It includes the high-level quantum programming language Q#, a set of libraries, simulators, support for Q# in environments like Visual Studio Code and Jupyter Notebooks, and interoperability with Python or .NET languages.

As quantum systems evolve, your code endures.

Learn more at https://azure.com/quantum

Prepare your organization

Tackling the world's toughest challenges requires computational power that exceeds that of today's most powerful computers. Where classical computing may take a billion years to address some of these challenging problems, quantum computing has the power to solve these problems in weeks, days, or even hours.

1. Find relevant use cases for your business

See how organizations like yours are using quantum solutions. The Microsoft Quantum website has case studies that show how companies are using quantum technology for their businesses, today.

2. Build a quantum workforce

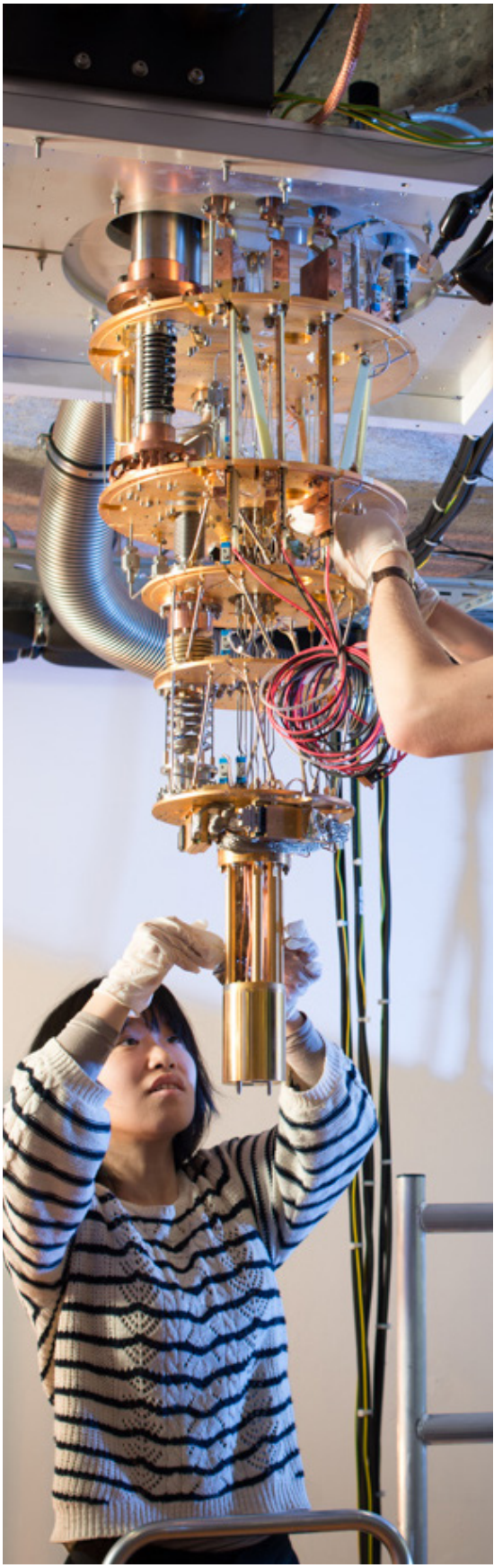
Ensure your organization is ready for quantum computing by assembling a quantum task force comprised of C-suite sponsors, business unit managers, and developers. Augment over time with quantum specialists and mathematicians that are familiar with applications and algorithms that are most relevant for your business.

3. Join the Microsoft Quantum Enterprise Acceleration Program

Microsoft offers the Enterprise Acceleration Program to develop high-value, custom quantum solutions alongside the world's best quantum talent. This is a paid offering for Microsoft's most advanced enterprise customers to accelerate quantum adoption through direct collaboration with the Quantum team. Contact us to get started.

4. Experience impact today through Azure Quantum

Microsoft is building a full-stack quantum ecosystem, delivered through the power and scale of Azure's global cloud services platform. Apply to become an early adopter for preview access to Azure Quantum.



Authors

Dr. Brad Lackey

Senior Principal Researcher, Microsoft

Brad Lackey is a Quantum Solutions Architect, specializing in creating quantum and quantum-inspired algorithms to solve real-world industrial problems. He also does foundational research in quantum information theory, post-quantum cryptography, and quantum programming languages.

Raj Paul

Regional Industry Business Leader, Automotive Americas, Microsoft

Raj Paul serves as Microsoft's Regional Automotive Industry Business Leader for the Americas region. He has responsibility for developing Microsoft's Automotive Industry solutions portfolio, including joint solutions with key partners and go-to market initiatives. Raj is a passionate advocate of the connected world. With 20 years of experience in the Automotive industry, he has been involved in the evolution of vehicle connectivity—creating the in-vehicle innovations and infrastructure to connect owners and OEMs with their vehicles and with each other. Through his efforts in Telematics and Infotainment, he has helped create new Automotive experiences, new ways of connecting with customers and platforms that fuel Intelligence.

References

1. S. Mandrà, Z. Zhu, W. Wang, A. Perdomo-Ortiz, and H. G. Katzgraber, "Strengths and weaknesses of weak-strong cluster problems: A detailed overview of state-of-the-art classical heuristics versus quantum approaches," Phys. Rev. A, vol. 94, p. 22337, 2016.

2. Mass Navigation: How Ford Is Exploring the Quantum World with Microsoft to Help Reduce Congestion: https://medium.com/@ford/mass-navigation-how-ford-is-exploring-the-quantum-world-with-microsoft-to-help-reduce-congestion-a9de6db32338

3. Traffic flow optimization using a quantum annealer: https://arxiv.org/abs/1708.01625

4. Accelerating materials design with Azure Quantum: https://cloudblogs.microsoft.com/quantum/2020/01/21/oti-lumionics-accelerating-materials-design-microsoft-azure-quantum/