

Quantum Supremacy:

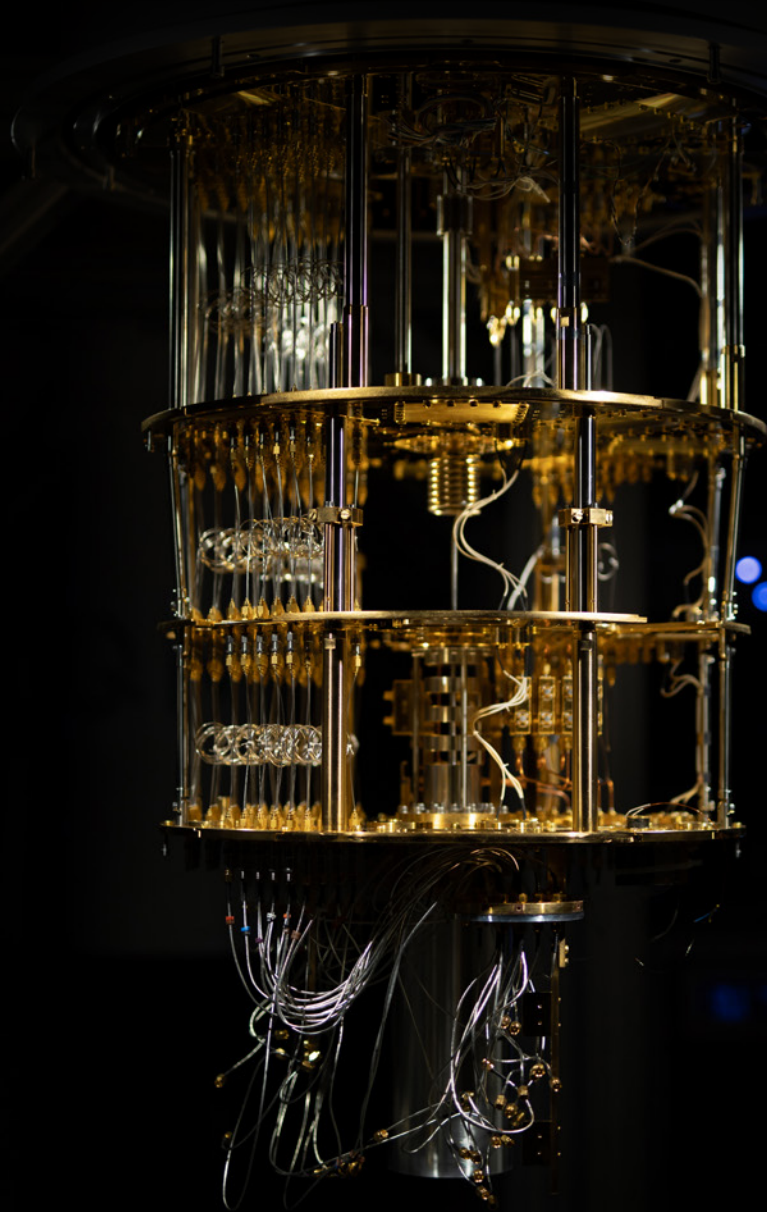
Preparing For the Coming Wave of Disruption

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Executive Summary

Quantum computing is poised to revolutionize industries by solving problems that are beyond the capabilities of classical computers. Whereas traditional algorithms address questions with calculations involving binary states, quantum computers simultaneously evaluate combinations of situations, making them far more powerful at scale. This paper explores the implications of these advancements across various applications as well as the challenges yet to be overcome. It then outlines the practical steps companies should take to prepare for the coming wave of disruption.



IQM Quantum Computer in Espoo, Finland (Credit: Ragsxl)

Introduction

Traditional computers ranging from the [Colossus](#) that helped win World War II to the most powerful current supercomputer, [Frontier](#), all rely upon sequential processing of individual bits of data, the binary ones and zeros that represent two alternative states. For the past 60 years, these classical computers have followed [Moore's Law](#), doubling in computational capacity approximately every two years. Despite these advances, there remains a series of complex problems such as modeling chemical reactions and optimizing routes that, at large scale, classical methods cannot efficiently solve.

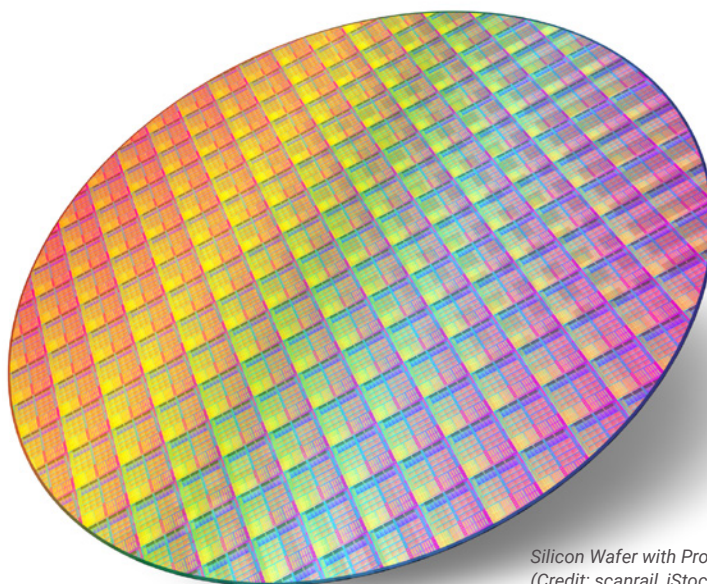
Quantum computers, by contrast, use quantum bits or qubits that simultaneously represent a superposition of states. By considering multiple situations in parallel, they can in principle become orders of magnitude more efficient in solving specific types of problems.

The term “quantum supremacy”—coined by a physicist in 2012—represents the point at which quantum computers can perform calculations infeasible for classical computers. The field's foundational concepts actually date back to the early 1980s, including a seminal [keynote](#) by [Richard Feynman](#) who suggested that quantum mechanics could be harnessed to simulate physical systems that classical computers could not efficiently model. Feynman's groundbreaking insight laid the essential groundwork for the field of quantum computing, envisioning a future where the inherent complexities of quantum mechanics could unlock unprecedented computational power.



Those who are not shocked when they first come across quantum theory cannot possibly have understood it.

- [Niels Bohr](#)



Silicon Wafer with Processor Cores
(Credit: scanrail, iStockPhoto)

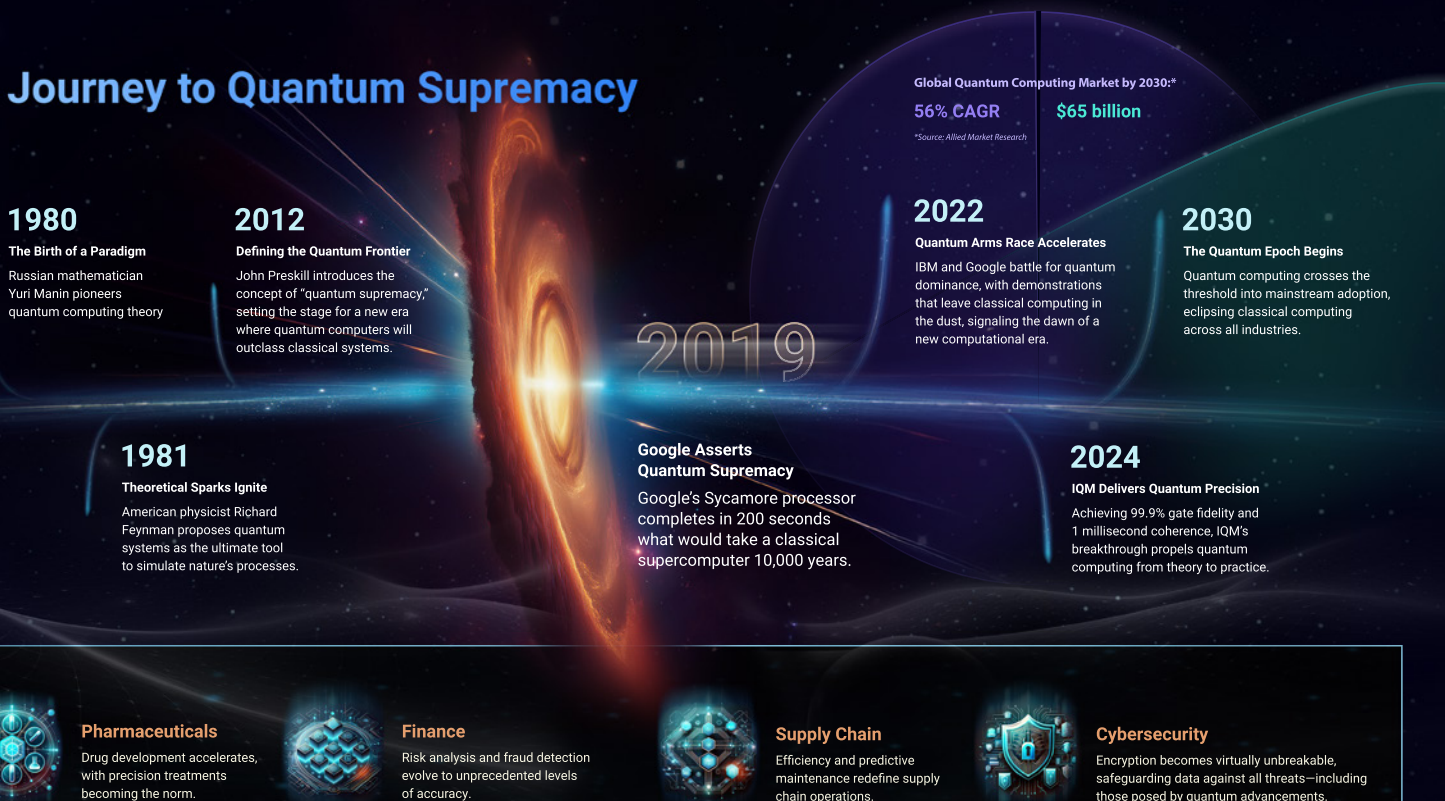
The Future is Near

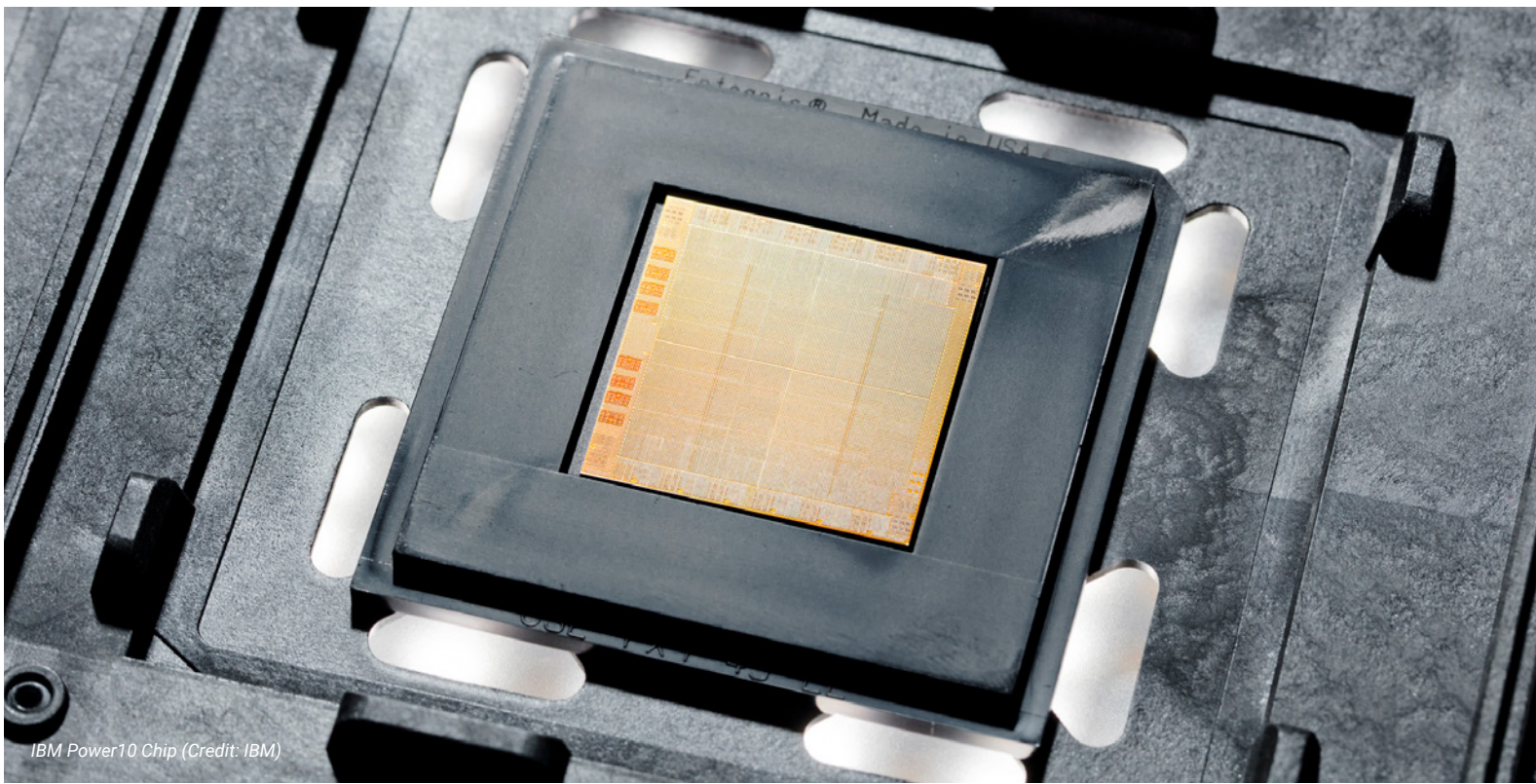
As the field of quantum computing progresses, we are witnessing a rapid acceleration in technological advancements and practical implementations. Researchers and companies worldwide are investing heavily in quantum technologies, striving to overcome the technical challenges that have traditionally hindered progress. These efforts have focused on improving error rates and computational stability, which are critical factors in achieving reliable and scalable quantum systems.

For example, on July 15, 2024, IQM Quantum Computers [announced](#) two significant milestones: achieving 99.9% 2-qubit gate fidelity and 1 millisecond coherence time. High-fidelity gates reduce errors in quantum computations, while longer coherence times allow for more complex calculations without significant information loss. These breakthroughs indicate that we are now moving from theoretical possibilities to tangible technological capabilities.

IQM's gate fidelity and coherence time achievements are important steps toward performant quantum operations, enabling the execution of more complex and accurate quantum algorithms. The enhancements demonstrate that the underlying fabrication technology is mature and ready to support the next generation of high-performance quantum processors, essential for fault-tolerant quantum computing and processors with higher qubit counts.

Journey to Quantum Supremacy





Strategic Opportunities

The advent of practical quantum computing holds the potential to unlock significant value across multiple use cases.

Supply Chain and Logistics Optimization

Quantum computing has the potential to revolutionize fields such as supply chain management by addressing complex optimization problems with which classical computers struggle. These problems include dynamic route optimization, which involves the notoriously difficult task of constantly adjusting travel paths given real-time changes in external conditions such as assigned workloads and traffic conditions.

Consider the classic [traveling salesperson problem](#), where someone needs to find the shortest path enabling them to visit each of a list of cities exactly once. The complexity of this problem can grow exponentially with the number of cities to be visited, just to generate a single ideal static route that minimizes overall distance. Real-world applications such as delivery truck routing are even more difficult, since dynamic routing is required to refresh routing to consider variations in requested stops, traffic congestion, weather, and fuel consumption as well as other constraints such as maximum vehicle capacities, delivery driver hours of service limitations, and a host of other factors.

Quantum algorithms can solve such dynamic optimization problems much more efficiently than classical algorithms. Volkswagen, for instance, performed a [pilot project](#) several years ago harnessing a quantum computer to dynamically optimize the traffic flow of a fleet of buses. This optimization involved both predicting passenger demand by stop as well as the optimal routes for each bus. Taken together, these capabilities hold the promise of significant cost savings, reduced environmental footprint, improved service performance, and enhanced customer satisfaction.

Luxury Retail Dynamic Inventory Optimization

Optimization use cases abound across multiple industries. In luxury retail, for example, a high-value need is dynamic inventory optimization. Luxury brands face the challenge of managing limited, high-value inventory across multiple regions while maintaining exclusivity and avoiding overstock or shortages. The complexity arises from fluctuating global demand, supply chain disruptions, seasonal trends, and the high cost of holding unsold luxury goods.

Quantum computing can dramatically transform this issue by solving large-scale, complex optimization problems in real-time. Using quantum algorithms, luxury retailers could dynamically manage inventory across global locations, optimizing stock levels based on real-time customer demand, predicted sales patterns, and supply chain variables like transportation delays or material shortages. The transformative return on investment (ROI) would come from:

- Reducing excess inventory in low-demand regions while ensuring high-demand locations are adequately stocked.
- Minimizing lost sales due to stockouts of popular items.
- Enhancing customer satisfaction by offering personalized stock availability in real time based on location and purchasing behavior.
- Lowering holding costs of unsold inventory while maintaining the brand's exclusivity.

This would result in a far more agile and responsive supply chain, driving revenue and reducing operational inefficiencies.



Global Airline Route Scheduling and Fleet Utilization

In the global airline industry, one of the most challenging problems is optimizing route scheduling and fleet utilization. Airlines must constantly adjust flight schedules, manage crew rotations, and allocate fleets to routes while considering fuel costs, maintenance schedules, weather, air traffic, and passenger demand. This problem is incredibly complex and computationally intensive.

Quantum computing can solve this by providing quantum-based optimization algorithms that handle vast numbers of variables simultaneously. By rapidly processing and recalculating the most efficient schedules for routes, fleet deployment, crew rotations, and maintenance in real-time, quantum computing could help airlines:

- Reduce fuel consumption by optimizing flight paths and aircraft deployment.
- Maximize fleet utilization by ensuring that each aircraft is used optimally based on maintenance requirements and route demand.
- Improve on-time performance by predicting and adjusting for potential delays due to weather, traffic, or other variables.
- Increase revenue by improving load factor (the percentage of available seats sold).

The return on investment would be significant due to lower operational costs, increased profitability from more efficient flights, and improved customer satisfaction from fewer delays and more reliable services.



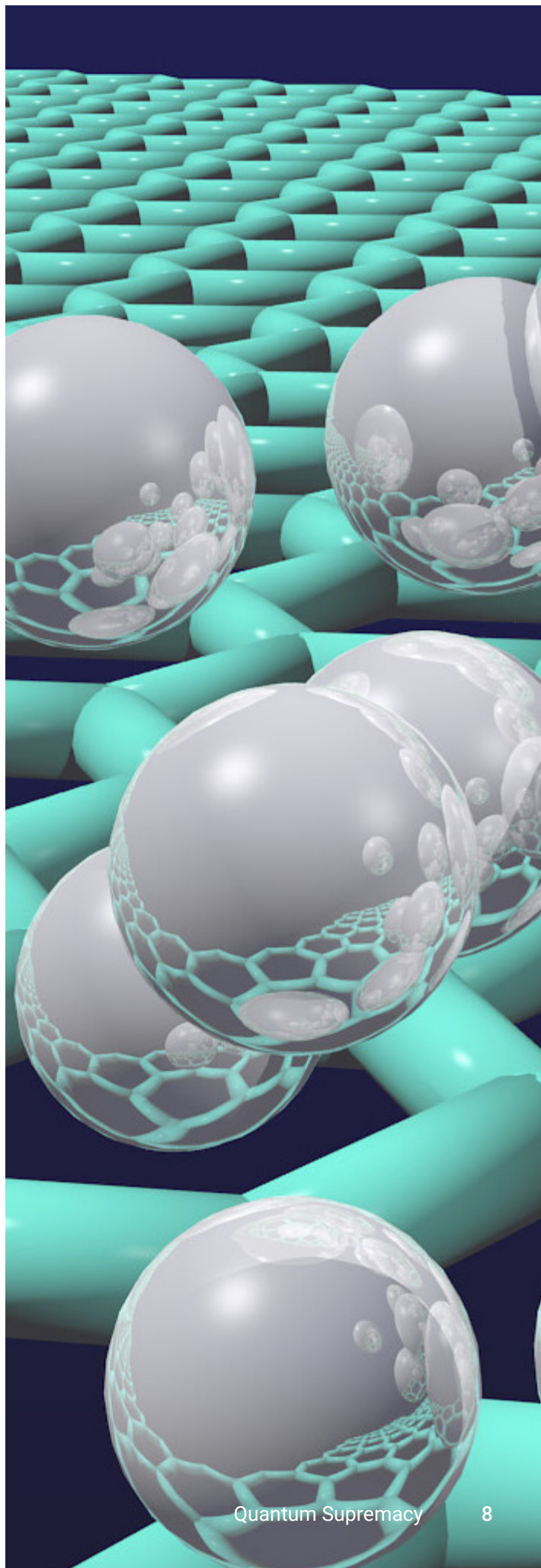
Mapping the World's Flight Paths and Airports (Credit: @PythonMaps)

Material Science and Drug Discovery

Quantum computing's ability to simulate molecular interactions at unprecedented scales offers transformative potential in both material science and drug discovery. Traditional drug discovery processes, for instance, are often lengthy and costly, involving extensive trial and error to identify promising compounds.

One representative problem in this field is determining the three-dimensional structure of proteins which in turn are essential to predict their biological functions. Due to the high cost of traditional experimental methods such as x-ray crystallography, only 170,000 proteins have been characterized over the past 60 years, compared to the 200 million proteins that are known to exist across all life forms. For this reason, DeepMind, a company affiliated with Google, recently applied deep learning techniques to develop [AlphaFold](#), a model to predict such structures. Notwithstanding the enormous advance, AlphaFold still suffers from significant limitations.

Quantum computing can dramatically shorten these experimental and computational timelines by precisely simulating the interactions between drugs and biological molecules, enabling the identification of viable drug candidates much faster. For example, Sanofi recently [established](#) a significant research collaboration with AQEMIA, an innovative pharmaceutical technology company pursuing the discovery of small molecule drug candidates via the application of quantum principles. This approach not only accelerates the discovery process but also reduces costs and increases the probability of success in clinical trials.



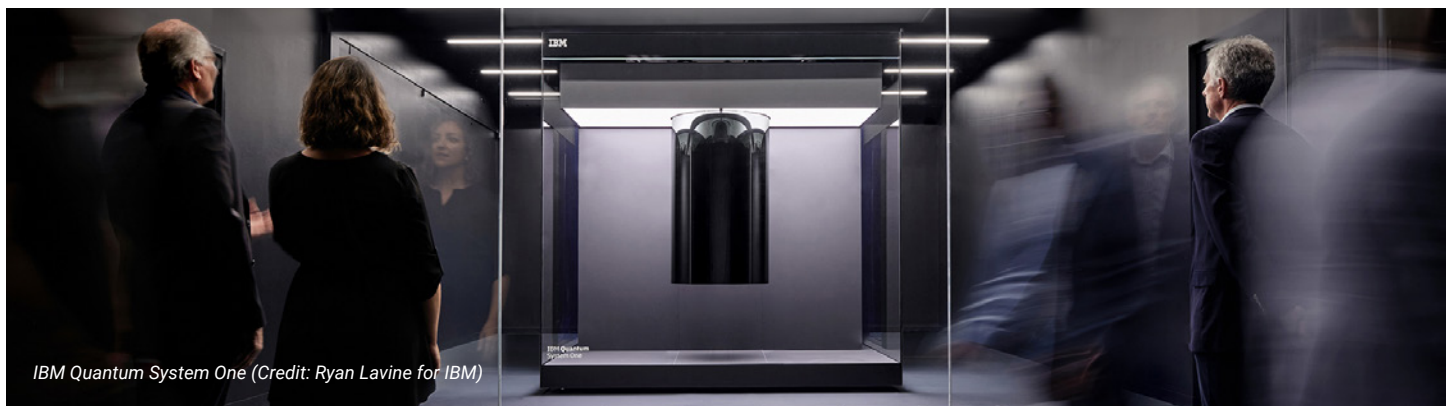
Cryptography and Security

Quantum computing presents both challenges and opportunities for cybersecurity. While quantum computers have the potential to break traditional encryption methods, they also enable the development of quantum-resistant algorithms, enhancing the security of digital infrastructures.

As quantum computers become more powerful, traditional encryption methods like [Rivest-Shamir-Adleman](#) (RSA) and [Elliptic Curve Cryptography](#) (ECC) will become vulnerable to attacks. The security of RSA, for example, hinges upon the difficulty of factoring large integers which are each the products of two prime numbers. Though classical computers struggle with this problem, here again quantum computers can excel, thereby rendering these encryption technologies obsolete.

Quantum-safe cryptographic techniques, such as [Lattice-Based Cryptography](#) and [Quantum Key Distribution](#) (QKD), offer solutions to these challenges by providing encryption methods that are resistant to quantum attacks. QKD, as its name suggests, uses quantum states to transmit information in ways which detect eavesdropping and are otherwise guaranteed to be secure.

[IBM](#) exemplifies companies at the forefront of research and development of quantum-safe cryptographic techniques. Indeed, its research scientists have been involved in the development of several standard approaches recently selected by the US National Institute of Standards and Technology (NIST) to implement new quantum-safe cryptographic algorithms. By implementing these techniques, IBM aims to protect its digital infrastructure from future quantum attacks, securing data even in a quantum-powered world.



Predictive Maintenance

Quantum computing's predictive capabilities extend to maintenance activities, which are crucial for operational efficiency. By analyzing sensor data and historical maintenance records, quantum algorithms can predict when machinery is likely to fail, allowing for proactive maintenance scheduling. This reduces downtime and prevents costly production halts.

[Airbus](#) is targeting quantum computing to enhance predictive maintenance for its aircraft.

Quantum algorithms will analyze data from thousands of sensors on an aircraft to predict potential component failures. This proactive approach should improve safety, reduce maintenance costs, and minimize aircraft downtime.

Financial Modeling

The financial sector stands to benefit immensely from quantum computing's ability to model and analyze complex financial systems with unprecedented accuracy. Quantum computing can enhance various aspects of financial services, including risk analysis, portfolio optimization, and fraud detection.

To get a sense of the challenge associated with traditional approaches, consider the usage of [Monte Carlo methods](#) to model stock options and complex derivatives. For each factor having a bearing upon the outcome, the model must randomly select an input value based upon its probability distribution, combine all inputs to calculate a deterministic result, and then repeat that process across a large set of iterations to generate an aggregate set of results. This approach becomes progressively more and more difficult to implement accurately as the underlying problem and variables become more complex.

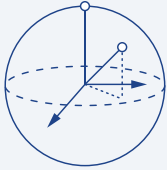
Financial institutions instead can use quantum computing to simulate various market scenarios, assess risks, and optimize investment portfolios more effectively. [Goldman Sachs and other large financial services enterprises](#) thus have been investing in quantum computing to enhance their financial modeling capabilities. By using quantum algorithms, Goldman Sachs can perform more accurate risk assessments and optimize its pricing and trading strategies. This leads to better investment decisions and improves financial performance.

Quantum computing can also improve fraud detection by analyzing large datasets for anomalies and suspicious patterns. Quantum algorithms can process data from multiple sources, such as transaction records, customer profiles, and external databases, to identify potential fraud cases more quickly and accurately. There have already been demonstrations of this emerging capability. A few years ago, for example, a quantum technology startup named [Multiverse Computing](#) used a quantum algorithm to improve fraud detection across a broad population of credit card payments.



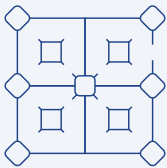
Outstanding Technical Challenges

Typical of any new fundamental emerging technology, there remain several obstacles to be overcome with quantum computing to unlock its full commercialization potential.



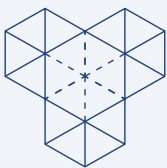
Qubit Quality and Control

For quantum computing to be viable, qubits must maintain coherence long enough to perform complex computations. Maintaining qubit coherence over longer periods remains a challenge, so research continues to develop more stable qubit designs.



Quantum Error Correction

Qubits are prone to errors, necessitating robust quantum error correction techniques. Despite these difficulties, scientists are optimistic about achieving reliable error correction within the next five years. Error correction involves using multiple physical qubits to represent a single logical qubit, enabling the detection and correction of errors. These advances in error correction are essential for the practical implementation of fault-tolerant quantum computing systems.



System Scalability

Scaling up quantum systems without increasing error rates remains another obstacle. Innovations in quantum interconnects and coherent communication across qubit arrays are crucial. Experts predict that solving this challenge could take approximately ten years. Researchers are exploring new materials, fabrication techniques, and architectures to improve the scalability of quantum systems while maintaining high performance and low error rates.

Implementation Considerations

Although the promise of quantum computing is enormous, the reality today for most organizations including even many large enterprises is that the field is not yet fully ripe for commercialization. Consider that with more than [\\$5 billion in cumulative investments to date](#), basic research and engineering remains outstanding to address the technical challenges discussed above and deliver practical applications for most use cases.

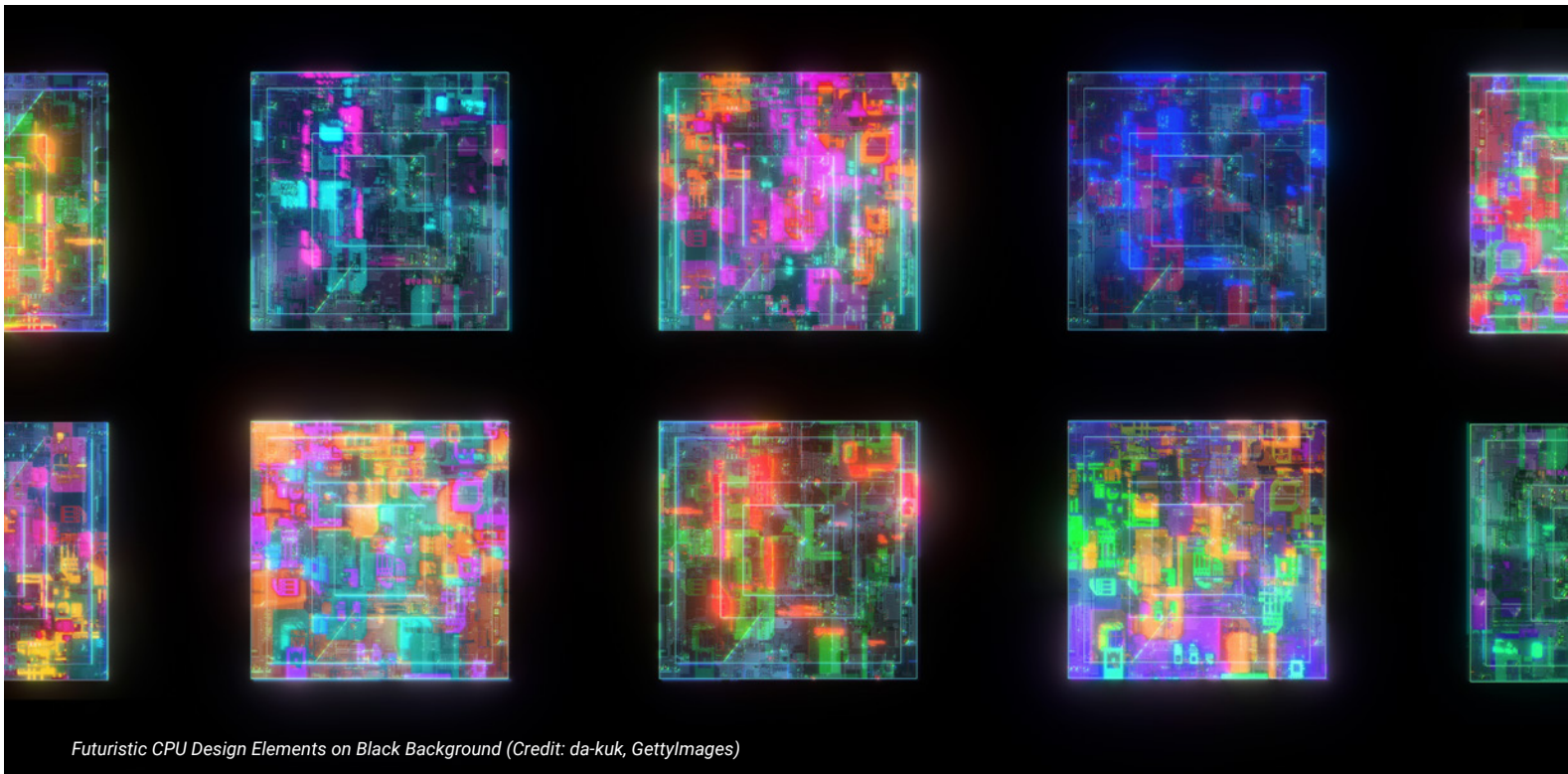
Senior executives at these organizations can nonetheless take several concrete steps to prepare for the coming wave of disruption:

- Before pursuing advanced capabilities such as quantum computing, they should ensure that foundational programs are in place including business process reengineering, digital transformation, data governance and stewardship, cybersecurity, and infrastructure management.
- From a human capital perspective, they should recruit and develop aggressive, cross-functional teams of business and technology professionals with modern skill sets who are eager to collaborate and drive performance improvement.
- Specific to quantum computing, these leaders should actively monitor developments relating to quantum computing and take precautionary measures such as pursuing post-quantum cryptographic techniques.



For those organizations already operating at a scale that justifies significant quantum investments, the pursuit of quantum capabilities requires a systematic approach:

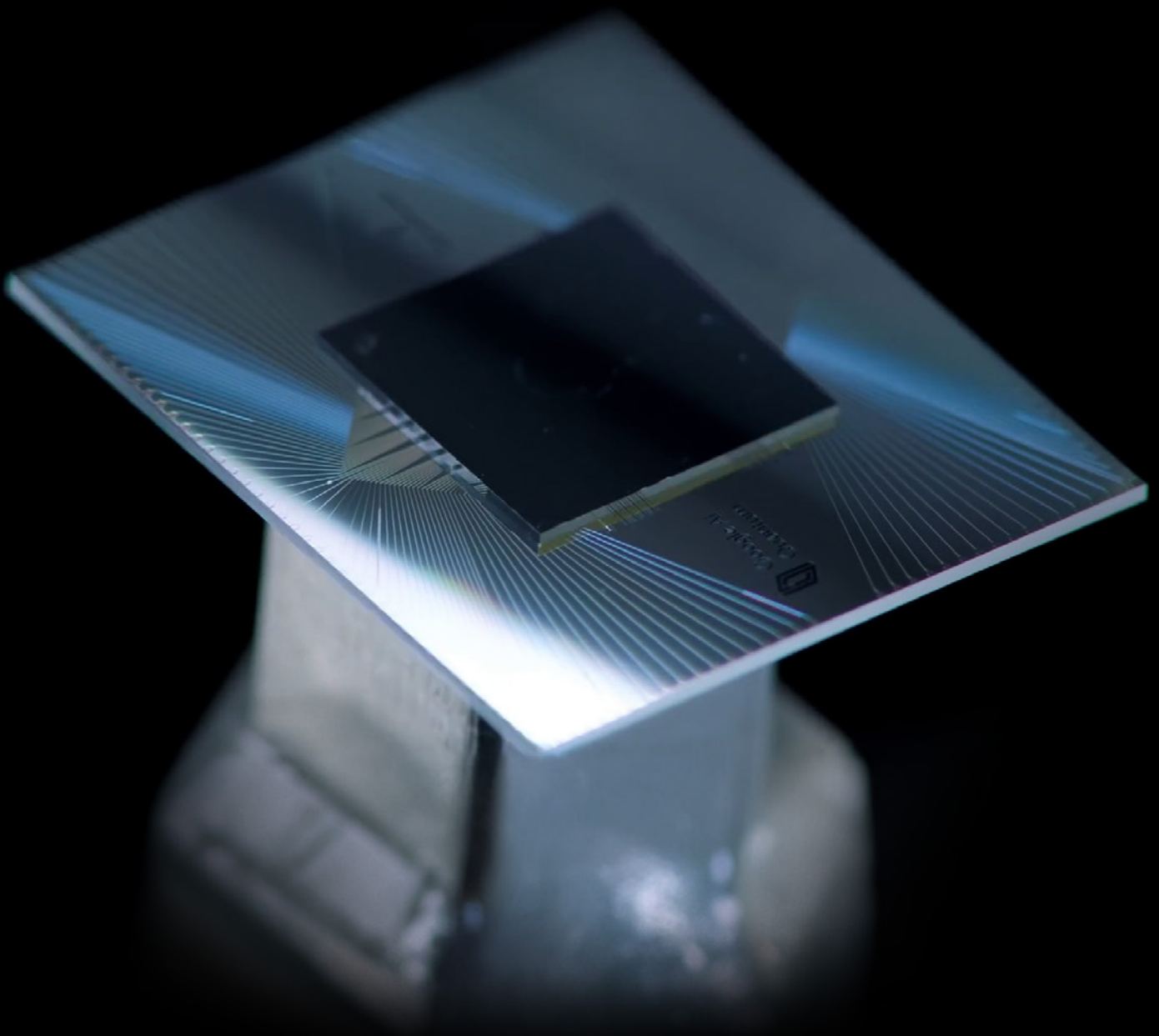
- One early step should be to identify specific high-priority problems that quantum computing can address within the organization for maximum impact. This involves assessing the current limitations of classical computing and determining where quantum algorithms can provide a significant advantage.
- To accelerate learning, enterprises should establish networks, collaborating with top academic institutions and research centers specializing in quantum computing. These partnerships facilitate knowledge exchange, joint research initiatives, and access to cutting-edge technology and expertise. Additionally, they can form industry partnerships, creating alliances with leading technology companies and quantum computing startups to stay at the forefront of technological advancements and integrate quantum solutions into their service offerings.
- When the time is appropriate, a major step is to build quantum infrastructure, including attracting the necessary talent to fuel a quantum computing program, investing in quantum hardware, and developing proprietary algorithms.
- Leading organizations should simultaneously articulate frameworks to guide their quantum programs including ethical standards governing societal impacts and other repercussions such as job displacements as well as overarching best practices.
- Armed with the capabilities above, quantum innovators can then execute specific pilot projects to test and refine quantum computing applications.



Futuristic CPU Design Elements on Black Background (Credit: da-kuk, GettyImages)

Conclusion

Advancements in quantum computing indicate a transformative future for a broad spectrum of applications and industries. Remaining technical challenges will dictate a cautious approach for most organizations over the near term, while those with the means and aspirations to innovate will face a challenging but rich set of opportunities.



Google Sycamore Chip (Credit: Google)

About P&C Global

P&C Global is the largest premier, full-service consultancy renowned for delivering end-to-end management consulting and technology services across diverse industries—from strategy through implementation. Unlike many firms that stop at presenting a strategy deck, P&C Global remains fully engaged throughout the entire process, ensuring that strategies are not only well-crafted but also meticulously executed to achieve real, measurable results.

We specialize in leveraging cutting-edge technologies, including quantum computing, to provide strategic insights and innovative solutions for our clients. We have:

- Acquired and operated our own quantum computer
- Developed proprietary quantum algorithms designed to tackle specific industry challenges with significant improvements in efficiency and accuracy compared to classical approaches
- Established a dedicated quantum computing lab to conduct cutting-edge research and development in a controlled environment, and
- Executed a series of pilot projects with select clients to test and refine quantum computing applications covering areas such as logistics optimization, financial risk modeling, and advanced cryptography.

[Contact us](#) to explore how we can help your organization navigate the future of quantum computing to maintain a competitive edge.





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