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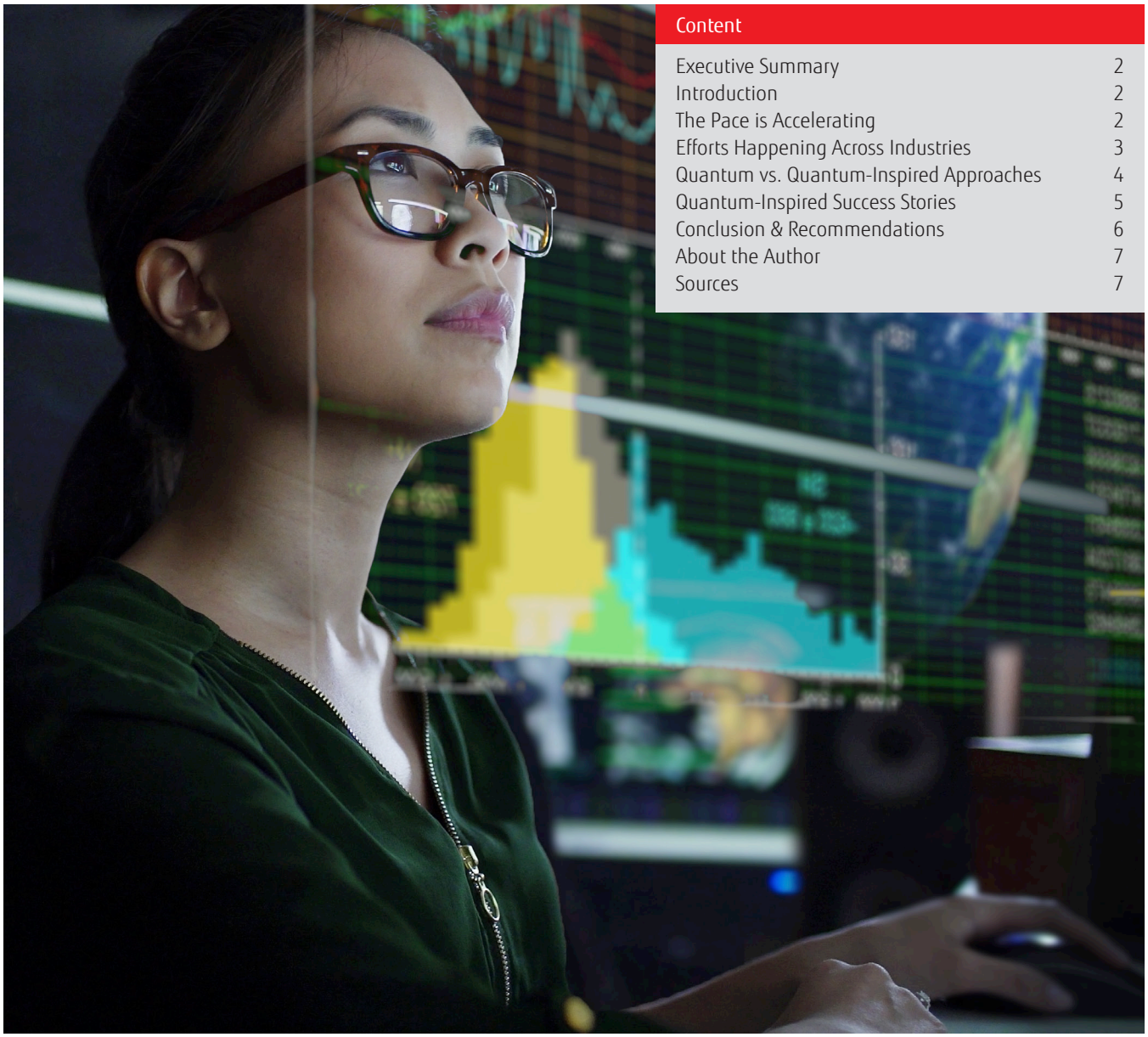
White paper

Why executives are adopting quantum-inspired computing solutions right now

Written by: Thierry Kahane, AI & Analytics Practice Leader for North America at Fujitsu



Content

Executive Summary

Business executives are taking notice as more and more large companies across industries announce achievements in quantum computing. Is this something that is of importance to their business? Should they start an effort in this space? And if so, how? This white paper is a practical introduction to quantum and quantum-inspired computing, answering common questions and providing actionable ideas for how executives can start taking advantage of the opportunities generated by these technology innovations.

First, we'll set the stage with a brief overview of the latest developments in the space. Then we'll describe how companies are undertaking efforts to apply these technologies, touching on the differences between quantum and quantum-inspired computing initiatives. We'll also share some impressive success stories from Fujitsu clients who have worked with us on quantum-inspired computing efforts across industries. Finally, we'll provide some recommendations for executives who want to start down this path or accelerate existing efforts.

Introduction

Both large and small businesses across industries have been impacted by the accelerated pace of business and technology changes over the past decade. These changes have been driven by a number of new technologies, as well as the new types of competitors and business models they've enabled. As a result, established players have had to seriously and more frequently rethink their corporate strategies, business models and technological capabilities.

The 2010s started with the wider adoption by businesses of what became known as MACS technologies–mobility, analytics, cloud and social–which morphed into the too-often-used term "digital transformation" and eventually gave way to the age of artificial intelligence (AI) and automation. As we entered 2020, most companies adopted or are in the process of adopting AI and automation to improve efficiencies or grow revenue–or both. And just as companies are starting to get their arms around what AI is and how it can help them achieve their goals, quantum computing has started to make headlines.

Fujitsu's AI & Analytics practice in North America brings innovative solutions to clients through advanced analytics, AI and quantum-inspired computing. Recently, at industry conferences, and in conversations with executives, a few common questions have been coming up regardless of a company's industry, size or place on the value chain.

- Why should we care or worry about quantum computing? Isn't it still 5-10 years away from true commercialization?
- What are our competitors doing with this technology? Are there tangible results at scale?
- Will this make all or part of our infrastructure and technology stack obsolete? If so, which part?
- How can we get started without disrupting our business and making a very large commitment?

To answer these questions, we'll first look at some of the latest and most well-publicized developments in quantum computing.

The Pace is Accelerating

There are some clear parallels between what's happening right now in quantum computing and what happened about five years ago with AI and machine learning. The pace of innovations and progress is accelerating, and more and more companies are launching real efforts to explore how this technology can be used to transform their business.

In December, Amazon announced Amazon Braket[1], part of Amazon Web Services. According to Amazon, "The fully managed service helps companies get started with quantum computing by providing a development environment where they can explore and design algorithms, then test them on simulated computers and different hardware technologies."

In November, Microsoft announced Azure Quantum[2], a diverse set of services that range from pre-built solutions to software and hardware, providing access to multiple quantum offerings on the market.

And in October, Google announced the results of an experiment it says proves quantum supremacy[3]. "Quantum Supremacy Using a Programmable Superconducting Processor" detailed the development of Sycamore, a new 54-qubit processor that performed a target computation in 200 seconds. Google determined that it would take the world's fastest supercomputer 10,000 years to produce a similar output.

Multiple industries also are focusing on quantum computing.

In the automotive industry, for example, Volkswagen announced in October that it's launching the world's first pilot project for traffic optimization using a quantum computer[4]. MAN buses in Lisbon have been equipped with a traffic management system that calculates the fastest route in almost real time for each of nine participating buses. The program's goal is to significantly reduce travel time and traffic flow, even during peak hours.

Ford announced in December that it has turned to quantum-inspired technology. According to CNET[5], the company used "quantum-inspired technology—though not an actual quantum computer—to test a traffic-routing algorithm that cut Seattle traffic by 73% and shortened commuting times by 8% in a simulation of 5,000 cars."

And in the financial services industry, several large firms—including JPMorgan, Goldman Sachs, Citi and Wells Fargo among others—are leading the way, using quantum computing for portfolio optimization, loan securitization, credit risk analysis, personalized marketing, and targeted recommendations/offers. A good overview of these initiatives is provided in an article published recently in the Financial Times: "Wall Street Banks Ramp Up Research into Quantum Finance."[6]

Efforts Happening Across Industries

In May 2019, a Fujitsu study surveying more than 350 global executives in six industries (financial services, manufacturing, life sciences, retail, transportation and utilities) showed a strong appetite for innovation in optimization. In "Is Business Ready to Make the Quantum Leap?" we found that:

- 81% of respondents agree that optimizing business processes helps companies tackle digital transformation and remain competitive
- 89% said they're held back from taking full advantage of optimization by the inadequate power of today's computing technology
- 66% want optimization services, not experimental quantum technology

In financial services, the report "Is Business Ready to Make the Quantum Leap?"[7] showed an even stronger appetite for better optimization through quantum and other novel computing solutions.

Companies that understand quantum computing's potential to generate significant business impact can take three possible avenues. Many companies are exploring more than one or even all three simultaneously:

1. **Quantum computing with quantum hardware:** Similar to the efforts by Google, Volkswagen and JPMorgan, many large companies are partnering with the leading technology providers of quantum computing to better understand and explore its applications. Due to quantum computing's current implementation challenges and operational limitations, these efforts have so far been focused on research projects, which are not expected to scale as needed for commercial applications for another 5–10 years.

2. **Quantum-inspired computing with traditional hardware:** This is the approach Ford took to develop its traffic-routing algorithm. With the help of large technology providers and specialized startups, companies can take advantage of advances in development of quantum algorithms, which can be run on traditional hardware. This method has demonstrated positive results across many areas, but is still limited in the type and size of problems it can address due to chip memory and processing speed limitations inherent in classical computing architectures.

3. **Quantum-inspired computing with special-purpose hardware:** This approach uses similar algorithms to the prior one, but the key difference is the hardware running the algorithms, in this case the proprietary quantum-inspired processor called Digital Annealer[8] developed by Fujitsu. This is a truly novel computing architecture, with at its core a digital circuit that leverages innovations in ultra-high-density circuit integration and high-performance processing with a specialized, non-Von Neumann, quantum-inspired architecture. This chip was purposefully designed and built specifically to more efficiently solve larger and more complex combinatorial optimization (CO) problems. Combinatorial Optimization occurs any time you have to find the maximum or minimum solution from a large but finite set of permutations or combinations. If you've heard of the Traveling Salesman Problem or Knapsack Problem, those are two of the most commonly known examples of CO problems.

While all of these approaches can generate valuable insights and coexist within one company—which can then benefit from using them for the right objectives—our experience shows that only the third path can currently scale sufficiently to tackle real-world business problems. When working with its clients, Fujitsu leverages quantum-inspired computing solutions running on its special-purpose Digital Annealer hardware to generate tangible business impact at scale with very high ROI by tackling portfolio optimization, delivery vehicle routing, message routing, manufacturing robot positioning, warehouse picking and order fulfillment, and more.

Quantum vs. Quantum-Inspired Approaches

Before exploring tangible examples and success stories, let's make sure there's a common understanding of the similarities, connections and differences between classical/traditional computing, quantum-inspired computing and quantum computing.

Quantum computing is the field of research and technology development that has seen tremendous focus and advancement in the past five years. The field explores how to harness the powers of quantum mechanics to build computers that operate on the basis of quantum bits—or "qubits." The concept of qubits, in contrast to digital bits—which, as we know, can have a value of only 0 or 1—is different, since a qubit can be 0 and 1 at the same time, or any value in between; it is about measuring probabilities. This is called "super position" in quantum computing. The ultimate aim of quantum computing is to be able to tackle much larger problems, which can't be handled by classical computing architectures, even the largest high-performance supercomputers. The challenge is that operating a quantum computer is very hard and expensive, given its operationally complex requirements, such as absolute zero temperatures, etc., which means only the largest technology companies and well capitalized start-ups can afford to build and operate them and that they're sized below 70 qubits. Even the largest quantum annealers (a specialized sub-set of quantum computers) have only a few thousand qubits and their architectures lack the full connectivity to tackle the largest optimization problems successfully.

Quantum-inspired computing as a broad category is the field that aims to avoid these challenges and still generate some of the benefits today that actual quantum computing will bring in the future. This includes efforts aimed at significantly improving our ability to solve larger and more complex combinatorial optimization problems, which are common across industries and aim to find the maximum or minimum solution from a large but finite set of permutations. Ford's traffic optimization effort is a great example of solving a combinatorial optimization problem by leveraging quantum-inspired computing.

To power its accomplishments in complex combinatorial optimization, Fujitsu's Digital Annealer leverages innovations in ultra-high-density circuit integration and high-performance processing. The groundbreaking architecture is inspired by the key characteristics of quantum computing—superposition, quantum tunneling and entanglement—enabling the Digital Annealer to evaluate very large numbers of potential options simultaneously and delivering lightning-fast answers. The current-generation Digital Annealer has 8,192 digital bits, which substantially expands the scale of problems that can be solved while increasing its precision and performance[9]. This solution has proven to be best in class for finding the absolute/very good minimum or maximum fast when there is an extremely large number of possible combinations (more than 10^100). Many times, we've found that these are problems that can't even be solved with today's largest and fastest classical computers[10].

The good news for executives making the decision about which path to embark on is that there is a strong commonality between the algorithms needed to adopt these two different approaches. The quantum annealing and digital annealing algorithms are basically identical, so if you start with one approach, its algorithms can be leveraged for the other approach. That's why, at Fujitsu, we consider quantum-inspired computing as a good bridge to the future of quantum computing, in two ways:

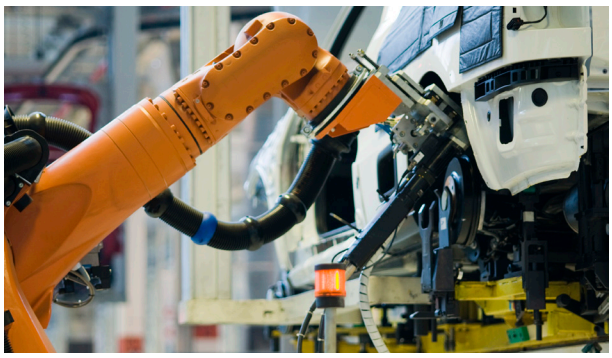
- We can solve problems today that can't be solved with general-purpose classical computers and that also can't yet be solved with quantum computers. The Digital Annealer is a solution that stands on its own—now and in the future—even if you never transition to actual quantum computing (due to ROI considerations, etc.).
- Any algorithms we develop on quantum-inspired computing platforms such as the Digital Annealer, can be reused on future quantum computers when they come online. There is no throwaway development work, and you'll be able to transition seamlessly to using quantum computing after having used the Digital Annealer, which acts as a true bridge to that future.

Now that we have a better understanding of what quantum-inspired computing is and how it works, let's bring this concept to life in the next section with three recent Fujitsu client success stories across multiple industries.

Quantum-Inspired Success Stories

Fujitsu is fortunate to have had the opportunity to work with some of the largest and most visionary companies in the world to demonstrate the value of the Digital Annealer in solving the largest and most complex combinatorial optimization problems. These clients have experienced the real impact this solution makes and have understood the high ROI they can generate from adopting it.

Car Manufacturer–Robot Positioning & Movement for PVC Sealing of Cars



Challenge: Paint shop operations generate a large part of car assembly costs, and as part of that step, cars have to undergo PVC sealing to make them waterproof. Multiple robots work in parallel to seal a car's body in as little time as possible, with the aim of constantly finding optimized paths to guide the robots' movements in near real-time. The less time needed in the paint shop, the more cars they're able to move through this crucial step in the process.

Solution: The complexity of tackling the optimization of the robots' movements depends on how many seams can be taken into account at one time. For example, seven seams will generate ~46,000 possible combinations[11], the maximum problem size our client could tackle with a real quantum computer. Using the Digital Annealer, Fujitsu was able to increase the number of seams to 64, which increased the number of possible combinations that were evaluated in near real-time to $1{,}83 \times 10^{106}$.

Benefit: The Fujitsu Digital Annealer was proven to handle much larger problems much faster than both classical and quantum computers. This resulted in faster completion of this complex sealing activity and the ability to move cars more quickly through the production process. The demonstrated time saved corresponds to several millions of dollars in savings per year and per production line.

Main Incubator, R&D Unit of Commerzbank–Optimization of Vehicle Loan Portfolio Securitization[12]

Challenge: Receivables from leasing contracts are sold to investors to optimize liquidity management for banks and leasing companies. They are offered by banks as tradable securities, with bundles of securities categorized by risk profile and other factors. The bundling of the underlying assets into the tranches of the resulting tradable securities is a complex combinatorial optimization problem.

Solution: Fujitsu used the Digital Annealer to drive selection and bundling of several thousand vehicle leasing assets for a securitization portfolio. Factors taken into simultaneous consideration included regulatory requirements, absolute volume limits and percentage limits for specific asset characteristics in order to achieve better risk diversification.

Benefit: The Digital Annealer successfully optimized the bundling of receivables, giving Commerzbank the ability to fully realize the potential value of the securities issued. The project demonstrated the Digital Annealer's ability to optimize portfolios with thousands of assets much faster than with traditional methods. Additionally, Fujitsu showed overall improvements measured by the total portfolio risk and value. As a result, the client is now exploring how to leverage the solution to optimize tens of thousands of assets to further increase the portfolio's overall value.[13]

Quantum-Inspired Success Stories continued

Toray Industries (Pharmaceuticals)—Optimizing Stability of Protein Molecular Structure[14]

Challenge: As part of drug research and development, the structure of proteins is determined through experimentation, and chemically crystallizing and stabilizing proteins is a difficult process. Consequently, to overcome lengthy research intervals, researchers look to computer modeling to predict the optimal combinations of different novel molecular arrangements—what is known technically as the side chain conformation of proteins. The side chain structures of large proteins generates large numbers of possible combinations. For instance, the number of combinations would be 10 to the power of 100 when identifying proteins that have 100 side chains with 10 different conformations. The goal of this research was to identify the most stable structures among large numbers of possible identified structures in just a few minutes.

Solution: The client worked with the Fujitsu team to use the Digital Annealer to predict the most stable structures for side chain conformation of proteins. First, the known optimal combinations of side chain conformations for structures of small proteins were compared with the optimal solution for the same proteins provided by the Digital Annealer to confirm that they matched. Next, the Digital Annealer was used to predict the structures of large proteins that the client was previously unable to compute.

Benefit: Using the Digital Annealer, Toray and Fujitsu demonstrated that we can extract and search the entire molecular structure, leading to more efficient drug discovery with faster and more accurate searches. The client was excited that "The problem of the large proteins, which a general-purpose computer failed to solve after three to four hours of computation, was solved in about 20 seconds by Digital Annealer. ... We were able to arrive at answers which were out of reach using the conventional way."

Conclusion & Recommendations

As explained in this white paper, quantum computing is quickly moving from the realm of academic and research institutions to the commercial world. Given its potential for delivering significant benefits, as well as for being a disruptive force across many business areas, it's imperative that executives incorporate quantum computing into their agenda from both strategic and emerging technology perspectives.

At Fujitsu, we're continuously advancing what can be accomplished with the Digital Annealer, including these recent milestones:

- The first successful on-premise implementation of the Digital Annealer solution
- Demonstrated scaling up to a 100,000-bit Digital Annealer solution to optimize production line scheduling for Fuji Film
- The next-generation Digital Annealer solution with up to 1 million bits, expected later in 2020

Given the fast pace of progress, the most important recommendation for your company is to get started now. There's no doubt that quantum computing will be available at scale in the near- to mid-term future, and large companies can't afford to risk being left behind. By starting a tangible effort to not just understand what quantum computing is but also where and how it can deliver value throughout their business, executives will ensure their organizations are ready when this future arrives. And to be clear, this effort should not be an IT initiative but rather a close collaboration between the business and IT. It's important that businesses drive the selection and implementation of the right high-value use cases while IT should contribute by adopting and making the capability available now and in the future.

To get a real understanding of what quantum computing can accomplish, it is most effective to focus on tangible accomplishments which go beyond strategic visioning exercises and workshops. That's why so many companies are choosing to work with Fujitsu. The real advantage of starting with a quantum-inspired engagement using the Digital Annealer is that, in addition to getting a better understanding of the technology itself, clients are able to deliver real business benefits with high ROI. And there is no better way to start your journey into quantum computing than by delivering significant value, which will ensure the organization stays the course and becomes a leader in this new and exciting field, pushing the boundaries of what can be realized with computers starting today.

For more information about Fujitsu Digital Annealer, visit www.fujitsu.com/global/digitalannealer.

About the Author

Thierry Kahane is the AI & Analytics Practice Leader for Fujitsu North America, focusing on driving impact with clients through the design and deployment of industry-focused, IP-based, innovative solutions powered by emerging technologies, such as Digital Annealer, AI/ML and Advanced Analytics.

He brings 20 years of relevant business experience, most recently having held senior commercial leadership roles with two VC-backed high-growth AI/ML technology firms. Previously, Thierry worked for 16 years in management consulting at Cognizant, Capgemini and Deloitte, where he built and led teams articulating and delivering strategic value to customers across financial services, healthcare/ pharma and other industries with a focus on innovation, digital strategy and transformation, analytics and automation.

Thierry holds an MBA in Finance & Management from Columbia University and an MA in Commercial Engineering from the Solvay School of Management.

He can be reached at: Thierry.Kahane@fujitsu.com

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Contact

FUJITSU AMERICA, INC.
Address: 1250 East Arques Avenue Sunnyvale, CA 94085-3470, U.S.A.
Telephone: 800 831 3183 or 408 746 6000
Website: www.fujitsu.com/us
Contact Form: http://solutions.us.fujitsu.com/contact
Have a question? Email us at: AskFujitsu@us.fujitsu.com