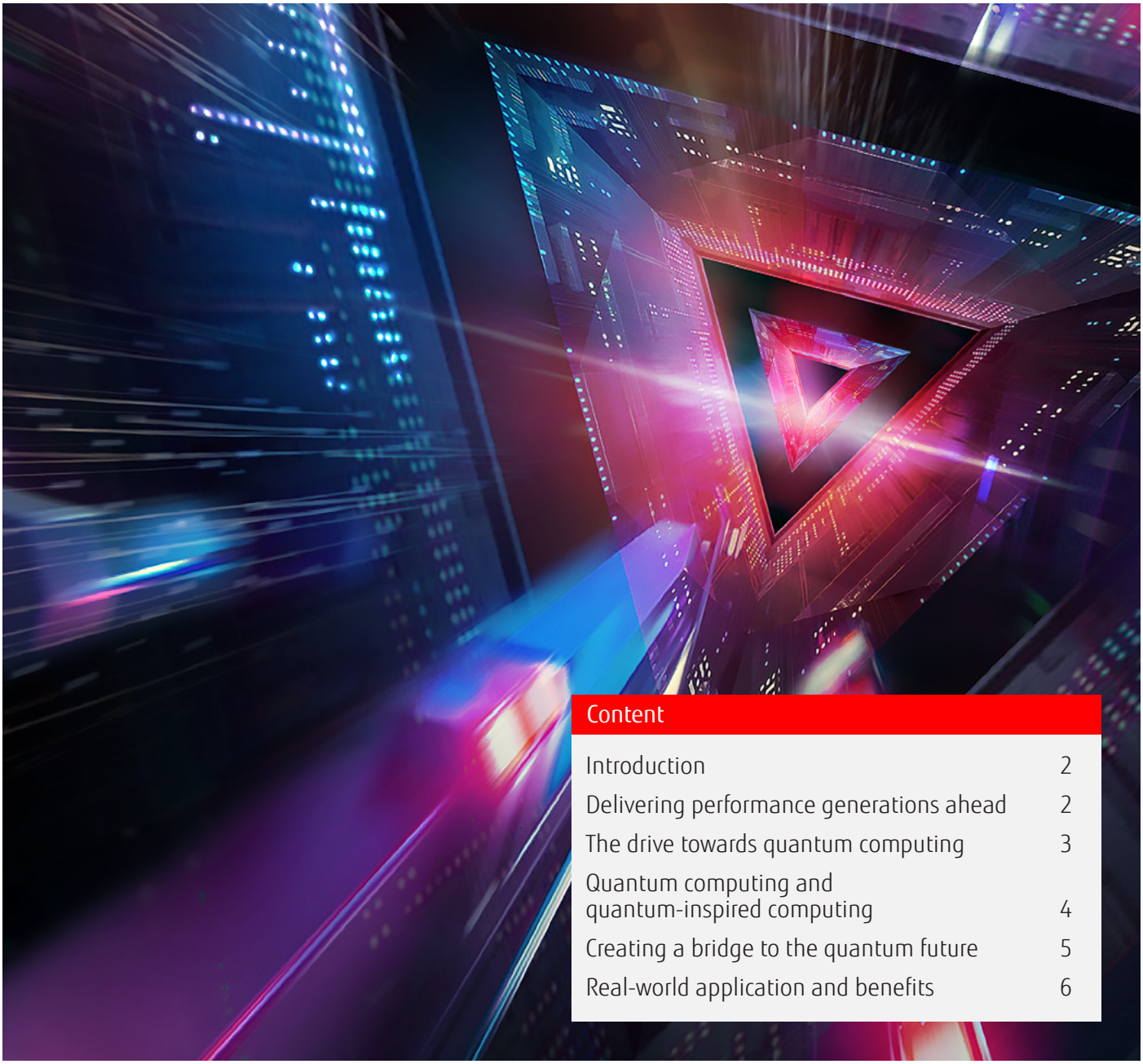
FUJITSU

White Paper
Quantum future – quantum present

Quantum-inspired computing leading the path to new disruptive markets.



Content

The idea that we might ever achieve optimal solutions to various problems in society and business was seemingly getting away from us. Operations and processes connected over the internet lead to an ever-increasing thirst for automation, machine intelligence and cloud computing, to name a few possibilities. And while greater connectivity opens up a new horizon of possibilities, it also generates a corresponding growth in complexity. While, classical computing-based solutions have been able to contribute immensely to this growth, there are limitations when it comes to specific complex, large-scale so-called 'combinatorial optimization' problems - which we will define and explain in this paper.

Using classical computers to find the optimum sequence in a process that drives out inefficiencies and improves productivity is possible when the number of variables is limited. However, when the process involves too many variables, they cannot reach an accurate answer by evaluating all possibilities fast enough and accurately enough to gain any practical benefit. The total cost, energy and time required would be unfeasible, as traditional computers, even supercomputers, are reaching their limits. This is primarily because the fundamental property of a traditional computing processor is based on sequential processing.

As the boundaries of classical computing come into view, there has been increasing research and investment in the field of quantum computing. The principle of quantum computing is not sequential and it has the potential to evaluate all possible solutions simultaneously. Unsurprisingly, many CTOs in areas as diverse as manufacturing, financial services, utilities, pharmaceuticals and government are taking a hard look at quantum computing as a possible means to overcome this looming optimization bottleneck, and to resolve many problems in business and more broadly in society.

When it is eventually ready to move out of the laboratory and solve practical real-world problems, quantum computing may be able to solve such challenges. But it's not yet ready to solve them from a scale, accuracy, applicability and commercial perspective. Fujitsu's 'Quantum-Inspired' computing, on the other hand, is available now and delivers optimization calculations with speed, precision and at a scale that true quantum computing is not able to achieve today.

Delivering performance generations ahead with quantum-inspired computing today

Recently, Fujitsu experts helped its automotive OEM customers explore complex optimization solutions that one of its customers described as "unsolvable with linear upgrades of the technology we have today". They went on to explain how – some years earlier – the research and investigation of traffic optimization for autonomous cars quickly made it clear that the calculations involved surpassed the abilities of currently available computing power.

Using current computing technology, it might be possible to make a one-off optimization calculation – given enough time. However, traffic is always in flux. An optimal calculation won't be valid for more than a few seconds as accidents, new journeys, essential maintenance and variable speed limits – to name a fraction of the possible complications – continually change the dynamic picture. Repeating an optimization every second could only be envisaged by making a switch to quantum computing. Or so it was believed.

What brought this particular automotive OEM to Fujitsu was its answer to specific complex challenges for automotive manufacturers using Fujitsu's new Digital Annealer – a quantum-inspired computing solution that is ready to use today. Fujitsu's team and the customer jointly tested Digital Annealer to learn and understand its potential by solving challenges including job shop scheduling, optimization of car mirror design and real time optimization of robot positioning in chassis welding. In the 'paint shop', which is one of the costliest processes in car manufacturing – contributing to an average of 40% of the total cost of manufacturing[1] – PVC seam-sealing by robots has been a particular focus of optimization efforts.

Currently, prototype quantum computing solutions addressing this challenge are able to compute optimization routes for about seven seams. The Digital Annealer is already fully handling 64 seams today, with even higher capabilities already in sight. This increase from seven to 64 seams isn't just nine-times the number of seams. The number of possible trip combinations to choose from increases by a factor of 10^{100} which is far beyond the assumed number of atoms in the whole universe. Naturally, this manufacturer was able to see immediately the huge potential in identifying the optimum welding round-trip for seam-sealing using Digital Annealer – and fully-handling 64 seams today is resulting in the manufacture of more cars with the same resources and in the same amount of time.

And away from manufacturing, in the world of financial services, NatWest bank has been using Fujitsu's Digital Annealer to solve a highly complex portfolio optimization challenge. This task needs to be undertaken regularly by the bank, and by using Fujitsu's Digital Annealer service it was able to do so at 300 times the speed of traditional methods, whilst providing an even higher degree of accuracy. NatWest is engaging with Fujitsu to help portfolio managers optimize the composition of the bank's £120bn High-Quality Liquid Asset (HQLA) portfolio. HQLAs are assets such as cash and bonds that every UK bank must hold as a buffer in case it runs into financial trouble, translating into another opportunity for NatWest to achieve significant market differentiation.

1. Assessment of Automotive Coatings Used on Different Metallic Substrates, W. Bensalah, N. Loukil, M. De-Petris Wery, and H. F. Ayedi, https://www.hindawi.com/journals/ijc/2014/838054/

The drive towards quantum computing

Let's take a step back to understand the prize on offer here. What these progressive thinkers are reaching for is the ability to improve processes by solving a class of problems known as **'combinatorial optimization'** – the process of identifying the optimal solution by evaluating each possibility from a finite but extremely large set of options. Until now, in tackling any combinatorial optimization process there has been a trade-off between precision and risk. Seeking high precision used to imply the need for more time to calculate the answer, while accepting a 'good enough' answer introduced an increasing amount of risk. The more precise the calculation you can achieve, the more cost-efficient the final process will be, leading to a game-changing opportunity to gain a competitive advantage.

It's a bit like old-school sailing calculations before the advent of sonar and GPS. When working out the clearance under the ship at any point in a tidal pattern, it was wise to leave a margin of error, even at the expense of a slightly longer journey, just in case the calculation was not precise enough. The risk, cost and inconvenience of running aground was not worth contemplating.

But the calculations involved are based on a mind-boggling number of variables and possibilities. Let us take a simple example to show how quickly combinatorial optimization variables can spin out of control. Calculating the most valuable combination of 40 out of 100 items to put in a backpack for a trek, results in an enormous number of possibilities, exceeding one million times the number of stars in the universe[2].

This would be impossible to solve quickly if you tackled each possible combination in a linear sequence. But quantum and quantum-inspired computers don't do that – they assess all the possibilities simultaneously.

It is this potential to overcome the limitation of conventional computing that explains why many of the world's major enterprises are now investigating quantum computing. In automotive manufacturing, the major OEMs, including Daimler, Ford and Volkswagen, have all announced quantum computing programs. Pharmaceuticals companies, including Amgen and Biogen, and chemicals companies are looking at areas such as molecular matching for new drug and materials discoveries. Utility companies are aiming to optimize ROI from new asset investments, while banks, such as NatWest and BBVA, and insurance companies are seeking to optimize portfolio and credit risk. Governments too are fascinated by the potential to achieve climate change targets faster, for example by optimizing transport systems to reduce pollution.

This is just the beginning. The scope for disruptive change from combinatorial optimization by quantum and quantum-inspired computing will stretch across industries, businesses and use cases, with the early adopters on this journey already in the front seat.

2. Single items have interdependencies. For example, a stand-alone item - such as a box of nails – has a low value, but this increases when combined with a hammer. The number of stars in the universe is assumed as being 10^{22}.

Quantum computing and quantum-inspired computing

The idea of a quantum computer goes back 40 years, when physicists familiar with quantum theory began to speculate whether it might provide the basis for encoding information. In quantum superposition, to take one example, objects can be in two (or more) states at once – as popularized by the thought experiment known as Schrödinger's cat. If this superposition of states could be harnessed in a computer, you would have the ability to simultaneously calculate all possible combinations of results.

Despite initial skepticism, we now see various kinds of quantum computers being used for experimental testing – and the potential is awe-inspiring. The only problem is, it remains some distance in the future. Optimists think perhaps five years – others say 10, 15 or even 20 years away.

One thing is clear: today quantum computing remains experimental, expensive, complicated and temperamental, and requires very specific operating conditions in order to compute and provide output – including power and cooling requirements that would drive temperatures lower than in outer space. As MIT professor Isaac Chuang puts it: "The thing driving the hype is the realization that quantum computing is actually real. It is no longer a physicist's dream—it is an engineer's nightmare."

In order to produce the correct output for a problem, quantum bits must remain in a quantum state at near absolute-zero temperatures, free from any outside interference, including cosmic or magnetic rays. Get this wrong and the qubits collapse out of their delicate entangled state, losing all quantum acceleration and of course also rendering any calculation impossible. To emphasize just how difficult this is, when an IT company recently unveiled a 50-qubit quantum computer to great acclaim, it featured the ability to preserve a quantum state for an industry-record time: 90 nanoseconds.

The fragility of these quantum states makes true quantum computing prone to error and creates a corresponding need for error correction. This consumes a sizable proportion of an already sparse pool of qubits, making it impossible to solve large scale problems and hence quantum computing has been restricted to research purposes only.

But what if it were possible to harness 'quantum-like' capabilities on existing computer architectures today? Fujitsu's scientists were keen on finding how to solve these critical problems today and realized that the software being developed for quantum computers could be applied to digital architectures. Based on this insight, Fujitsu created the Digital Annealer, a unique circuit design inspired by the quantum phenomena. It has a fully-connected architecture enabling the free exchange of signals across all bits and can, therefore, solve large-scale combinatorial optimization problems instantly.

The power of the Digital Annealer lies in Fujitsu's quantum-inspired digital architecture that leverages innovations in ultra-high-density circuit integration and high-performance processing. Digital Annealer is delivered to customers as an end-to-end solution, deployed anywhere from cloud to edge. The Digital Annealer solution today supports an 8,192-bit fully-connected architecture with a promising roadmap to support a 100,000-bit scale solution. The 8,192-bit Digital Annealer solution not only comes with a high precision of 64 bit (the highest accuracy available in the market) but also with the capability of partitioning.[3] This means – depending on the problem scale, you can configure the system in different configurations as here:

1x 8,192 partition, 2x 4,096 partitions, 4x 2,048 partitions, 8x 1,024 partitions

And each partition can run one problem at a time. This gives Digital Annealer a unique advantage of parallel processing of different problems set on different scales at the same time.

This ground-breaking solution is inspired by the key characteristics of quantum computing: superposition, quantum tunneling and entanglement, enabling the Digital Annealer to evaluate multiple potential options simultaneously – and deliver lightning-fast insights.

Yet, from a practical perspective, the Digital Annealer operates at data center temperatures and does not need special cooling: in other words, it works with digital circuits at room temperature – without needing any specific expertise or a complex infrastructure to function.

Fujitsu has co-created the quantum- inspired algorithm for this new architecture, working with Toronto University, which has a leading research position in the field, and 1QB Information Technologies (1QBit), based in Vancouver, Canada, the leading commercial player in quantum software. This algorithm is compatible with those being developed for prototyping true quantum (quantum annealing or 'quantum gate') computers, meaning that solutions developed with Digital Annealer today will be compatible with quantum computers, when these eventually emerge.

This quantum-inspired technology, simultaneous processing and offsetting from local minimum optimal state capabilities allows FUJITSU Quantum-Inspired Computing Digital Annealer to instantly find the optimal combination of massively complex, previously unmanageable data variables. As we saw earlier, in the case of robot welding in vehicle manufacture, optimization of the seaming process - already underway with Digital Annealer - will boost profitability by allowing more cars to be manufactured in a given time and by reducing the need for additional resources in the paint shop process. Fujitsu has also applied this solution in its own factories, where the use of Digital Annealer has optimized inventory and reduced workers' traveling distances by 45 percent per month, with a consequent reduction in non-productive time.

3. Depending on the partition size, the precision bit may vary. For more details please contact Fujitsu sales.

Creating a bridge to the quantum future

Fujitsu Digital Annealer has been described by independent analysts as a unique opportunity to pre-empt quantum computing and achieve the benefits of optimization today, using current data centers. They talk about creating a "bridge" to the quantum future – taking advantage of the benefits of combinatorial optimization, while also learning how true quantum computing can be applied to future operations.

Fujitsu provides the Digital Annealer Solution as an end-to-end service in the cloud or on-premises solving any customer challenge that can be translated into a combinatorial optimization problem. And all this without needing the complex wrap-arounds associated with quantum computing, such as cryogenic cooling systems. The service is fully compatible with existing architectures and therefore fits into existing business workflows and processes.

The engagement model follows a fast, straight-forward three-step process that starts with a consultancy-led approach to identify the business challenge to be solved jointly and whether that translates into a combinatorial optimization calculation.

If it does, in the second step Fujitsu's solution support team maps that challenge onto a mathematical model called Quadratic Unconstrained Binary Optimization (QUBO), which is further translated to identify and fine tune the quantum algorithm. This then runs on the Digital Annealer solution to provide the precise answer to the problem in seconds or minutes – depending on the size of the problem.

In the third and final step, Fujitsu operates the customer's new Digital Anneal application, providing support and quality assurance of the system.

With quantum computing on the horizon, and a bridge to that quantum future now available through the Fujitsu Digital Annealer Solution, the next wave of disruption coming from combinatorial optimization is already upon us. While investment decisions on superconductivity quantum hardware are still some way off, there is now an opportunity to get ahead of the curve and start using quantum algorithms with Fujitsu's Digital Annealer and to stake-out a winning position in the upcoming quantum-disrupted market.

The technology is in place, proven, technically reliable and cost effective and the solution includes end-to-end support and services. Fujitsu is now inviting customers on to this journey to become one of the disruptors of the future.

> "a unique opportunity to pre-empt quantum computing and achieve the benefits of optimization today..."

Real-world application and benefits

FUJITSU Quantum-Inspired Computing Digital Annealer:

Transforming businesses today

All processes have the potential to be optimized. The ability to uncover and leverage efficiencies and insights will bring profound change and advantages in all sectors of the economy and government.

Among the pioneers already making headway, world-leading **car manufacturers** have engaged with Fujitsu for a range of optimizations including job-shop scheduling, engineering design and the optimization of robot positioning. As we have seen, in the automotive sector OEMs began with traffic optimization to enable autonomous driving in a congestion-free society, but have quickly branched out from there as they gain experience with quantum-inspired Digital Annealer. Battery development is in the spotlight, with the search on for high-density designs that could dramatically expand the capacity of batteries used in everything from portable electronics to vehicles. The time is right: Improvements in battery density have been running at just 5 to 8 percent annually.

In financial services, real-time optimization with the Fujitsu Digital Annealer has many applications for banks and insurance companies. In credit risk assessment of individuals and companies, it reduces risk by increasing the correlation of credit evaluation items while improving efficiency by reducing the number of credit characteristics to evaluate. Real time interest rate swap optimization in derivatives trading is another high gain option.

Other possibilities for digital annealing in financial services include calculating the optimum amount of cash and the most efficient route for ATM replenishment. Cash replenishment accounts for up to 60 percent of ATM network operating costs and optimization would improve profitability significantly at a time when ATM network operations are under pressure.

And using Fujitsu's Quantum-Inspired Digital Annealer, NatWest bank has completed a highly complex portfolio risk optimization calculation that needs to be undertaken regularly by the bank, at 300 times the speed of a traditional computer while providing an even higher degree of accuracy.

In the search for new substances and to develop new drugs, **chemical and pharmaceutical laboratories** use molecular similarity searching, which partially extracts molecule characteristics. Digital Annealer-powered research is able to explore entire molecular structures without relying on extraction, thereby enabling accurate, instant similarity searching and faster, potentially disruptive new product development. TORAY Industries, Inc. successfully tested Digital Annealer to accelerate drug discovery and biotech research. Its approach is to optimize molecular structure stability with Digital Annealer by predicting the most stable protein side-chain structures, with the aim of improving stereochemical prediction accuracy in target protein research. Elsewhere in this sector, Fujitsu is also running a joint research with Toronto University in advanced medical care for cancer treatment to improve cancer radiation therapy.

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In **transport and logistics**, Japan Post Co. Ltd. has been able to reduce its delivery fleet in a single city from 52 to 48 trucks. In collaboration with quantum software company, A*Quantum, Japan Post has leveraged the Fujitsu Digital Annealer to optimize transportation route combinations, truck types and cargo loads. The result has been the capacity to shrink the delivery fleet and reduce costs, while achieving faster delivery times and truck loading efficiency.

And in **the public sector**, cities and national governments are urgently looking to address the issue of traffic optimization. The potential benefits are significant: better air quality means lower levels of respiratory and other diseases, and increased citizen well-being. Lower carbon emissions feed through to national targets on emission reductions, enabling governments to focus their spending on other vital policy areas. More efficient journeys will raise productivity, reduce frustration and encourage economic growth.

Digital Annealer's ability to perform parallel, real-time calculations on unbelievably complex challenges like traffic optimization, stands head and shoulders above today's possibilities using classical computing. These struggle to perform the calculation at all. Early modeling suggests that digital annealing holds the potential to reduce traffic congestion by up to 40 percent, by dispersing traffic to less congested routes.

Fujitsu

Web: www.fujitsu.com/DigitalAnnealer

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