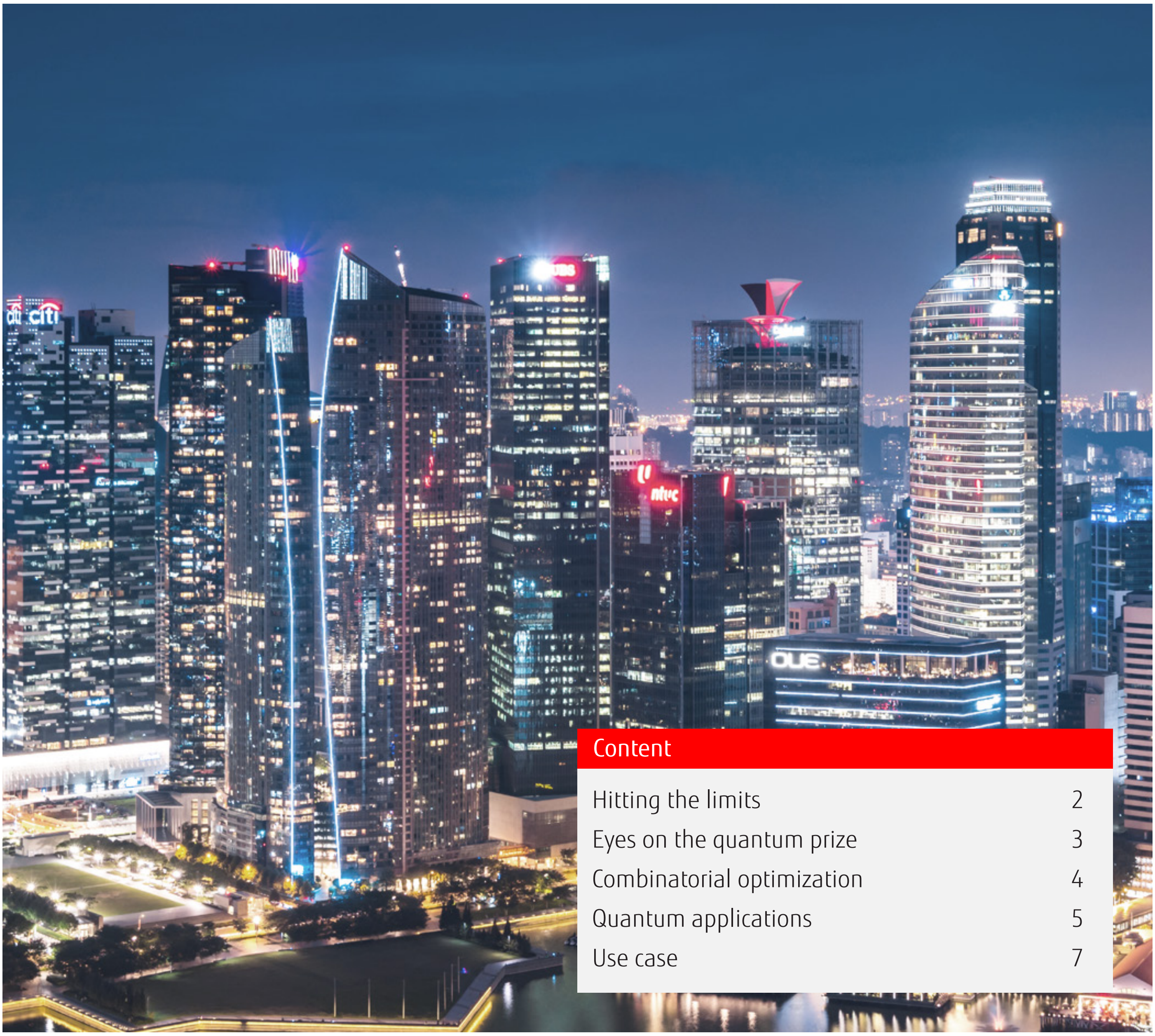
White Paper
The case for quantum and quantum-inspired computing in financial services



Content

What if it were possible to optimize short-term funds management or large portfolios of highly fluid assets in near real-time? Today, this would perhaps just be possible in limited circumstances, but once the number of assets in these calculations starts to grow even modestly, the laws of mathematics take over and the range of possible outcomes quickly spins beyond the reach of even the fastest supercomputers. But a new way of tackling these so-called 'combinatorial optimization' problems is removing current constraints, causing CTOs in financial services to take a close look at the emerging new classes of quantum and quantum-inspired computing.

> "Fujitsu is now helping NatWest bank solve some of its most complex, challenging and time-consuming financial investment problems"

Hitting the limits

When mathematical calculations get complex enough, they hit the limits of current computing, especially when it comes to optimization calculations. Here, the number of options to be tested in search of the best possible combination can quickly result in numbers that stretch out towards infinity. Until recently, these calculations could be so time-consuming that, by the time an answer was found, it was no longer relevant.

The complexities are mind blogging: in the case of traditional Data Encryption Standard (DES), today's fastest supercomputer would take around 21 billion years – or one and a half times the age of the universe, to calculate the correct prime factors of a number with 617 decimal digits (in other words, a 2,048-bit key. However, with a quantum computer this task could be manageable instantly.

Using 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, classical computers cannot reach an accurate answer fast enough to gain any practical benefit. The total cost and time required would be too large, 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 then, many CTOs in financial services organizations are taking a hard look at quantum computing as a possible means to unlock the gains available from optimization. Spanish banking group BBVA, for example, has noted that "...integrating the fundamentals of quantum mechanics into computer science will bring about a sea change in the depth and breadth of computing power."

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, applicability and commercial perspective. Fujitsu's 'Quantum-Inspired' Computing Digital Annealer, on the other hand, is available now and is helping NatWest Bank solve some of its most complex, challenging and time-consuming financial investment problems by optimizing its mix of high-quality liquid assets including bonds, cash, and government securities.

Eyes on the quantum prize

What these forward thinkers are reaching for is the ability to improve business processes by solving a class of problems known as 'combinatorial optimization', where the set of possible solutions is finite.

Until now, the goal has been to find ways to search efficiently for answers that are optimal, without having to try every possible one – in other words, taking a series of educated guesses. In tackling any optimization process, there is a trade-off between precision and risk. Seeking high precision once implied the need for more time to calculate the answer, while accepting an answer that is 'good enough' introduced an increasing amount of risk and the need for a security buffer. The more precise the calculation you can achieve, the less waste there is in the process.

If quantum computing can be made to work, the balance in this equation shifts – because it becomes possible to achieve a view that greatly reduces risk – and it's in this area that savings are achieved.

The idea of a quantum computer goes back to the late 1970s, when physicists familiar with quantum theory began to speculate whether it might provide the basis for encoding information. In quantum superposition, 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 calculate many possible combinations of results simultaneously.

Despite initial skepticism, we now see various kinds of prototype 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 – a more realistic assessment could be 10, 15 or even 20 years away. Sooner or later, production quantum devices will be available. Within 20 years, they may stop seeming exotic and enter the business mainstream. But right now, we are not there. Quantum computing remains experimental, expensive, complicated and temperamental, and requires very specific operating conditions in order to compute and provide output – including cooling requirements that are simply beyond the reach of even high-end data centers.

In order to calculate a solution, quantum bits need to stay in superposition at near absolute-zero temperatures, free from any outside interference, including cosmic rays or magnetic waves. 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 unveiled a 50-qubit quantum computer in late 2017 to great acclaim, it featured the ability to preserve a quantum state for an industry-record time: 90 nanoseconds.

Combinatorial optimization on digital architectures – Digital Annealer: a bridge today to the quantum future

But what if it were possible to harness quantum-like simultaneous calculation capabilities with state-of-the-art technology today? Fujitsu’s scientists were the first in the world to react to the realization that the phenomena in quantum computers could be emulated within digital architectures and created what it calls the Digital Annealer. It has a fully-connected architecture enabling the free exchange of signals between any two bits and can therefore solve large-scale, highly complex combinatorial optimization problems very quickly.

A convenient way to conceptualize the Digital Annealer is as a special accelerator to speed up combinatorial optimizations, integrated into an operational setting with conventional hardware in a hybrid environment.

The power of the Digital Annealer end-to -end solution lies in Fujitsu’s quantum-inspired digital architecture that leverages innovations in ultra-high-density circuit integration and high-performance processing. Digital Annealer provides up to 10,000 times faster performance than industry standard compute systems running with commercial servers,[1] and it already supports an 8,192-bit, fully-connected architecture with a promising roadmap to support a 100,000-bit scale solution. This ground-breaking offering is inspired by the key characteristics of quantum computing: superposition, quantum tunneling and entanglement, enabling Digital Annealer to evaluate multiple potential options simultaneously – and to 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 operates with digital circuits at room temperature, and fits into a data center rack – or can be run in the cloud – without needing any specific infrastructure expertise or a complex infrastructure to function.

Fujitsu has also developed the Digital Annealer’s core algorithm for this new architecture, which is compatible with those being developed for prototype true quantum computers, meaning that today’s Digital Annealer solutions will be compatible with future quantum computers, when they eventually emerge.

Fujitsu Digital Annealer has been described by independent observers as a unique opportunity to pre-empt quantum computing and achieve the first stage benefits of optimization today, working within a conventional datacenter environment. They talk about creating a ‘bridge’ to the quantum future – getting the benefits of combinatorial optimization today while also learning how true quantum computing can potentially be applied to operations in the future.

And the most forward looking financial services organizations are already stepping on to this bridge, including NatWest Bank (see use case on page 5), and others which are following advances carefully, including BBVA, which discussed Digital Annealer’s potential in a recent blog.

While investment decisions on superconductivity quantum hardware are still some way off, there is now an opportunity to not only build experience and know-how about quantum computers, but to solve real-world combinatorial optimization problems using the Fujitsu Digital Annealer bridge to quantum and to gain optimization insights and leadership.

1. The performance comparison was conducted by evaluating the quadratic assignment problem (QAP) on the Digital Annealer against a general purpose, multi-core, Xeon multi-processor system.

Quantum applications in financial services

Cash management optimization in the ATM network is one practical use case for quantum computing. Today, in banking, there is a real commercial advantage in operational efficiency and in managing short-term funds. For example, by calculating the optimum amount of cash held in individual ATMs and working out the most efficient route for cash replenishment, machine by machine.

Purely at the level of operational efficiency, cash replenishment costs account for between 35 and 60 percent of the total cost of operating an ATM, which makes optimization a key factor in improving profitability. Optimizing where the cash is in the network at any one time can also result in gains from interest from the Bank of England that is paid on cash within a 'bonded store' – highly secure locations from which cash is distributed to ATMs and banks - but not in an ATM. The mathematical problem is how to keep just enough cash in ATMs and banks to provide the service customers expect, while moving cash as little as possible in the network and keeping as much as possible in the bonded stores.

The possible permutations of amounts and routes across an ATM network of this scale, however, are daunting. Even if the total number of ATMs has now peaked, there are still 65,379 in the UK alone according to the Bank of England. Per calendar quarter, UK ATMs dispense around £44 billion spread over 628 million withdrawals, with an average transaction amount of £70[2]. Calculating the optimum solution to this puzzle, even for single bank-owned networks (the largest such network in the UK accounts for only about 10 percent of the total ATM estate – and the largest overall operator controls about 25 percent), has been unrealistic in a timeframe short enough to be able to respond on the ground. Until now, recalculating in real time and amending plans for a new optimized distribution to take into account any abnormal, temporary spikes in demand for cash in a particular city, district, or bank – and repeating the operation every time there is a material change in circumstances – defies, or rather, has defied current computing abilities.

Risk management is another important use case for the Digital Annealer. In **credit risk assessment** for banks and insurance companies, for example, the objective is to reduce credit risk by improving the credit rating accuracy of individuals or companies. This is achieved by evaluating the many variables provided by credit rating agencies, while maintaining the accuracy of the extracted credit evaluation data.

Currently, credit risk assessments are made at a point-in-time and then carried forward from that point onwards. Ideally, they would be real time and continuously updated. One significant barrier, however, is that – as the credit information used for evaluation increases – so the number of combinations increases exponentially.

Digital annealing can overcome these barriers, with the result that bank credit risk is reduced by increasing the ability to correlate credit evaluation items, making it easier to maintain credit rating accuracy.

Another risk management example comes in **derivatives transactions**, where interest rate swap optimization can theoretically be achieved via transaction netting interest rate swap agreements to reduce clearinghouse risk exposure in fixed and variable interest rate swap transactions between companies. However, due to the large number of interest rate swap combinations for transaction netting, it is extremely difficult to find an optimal combination that minimizes interest rate costs. Derivative transactions will often involve interest rate swaps across 20-30 currencies and continuously calculating which is precisely the optimal trade, in real time, is not currently viable.

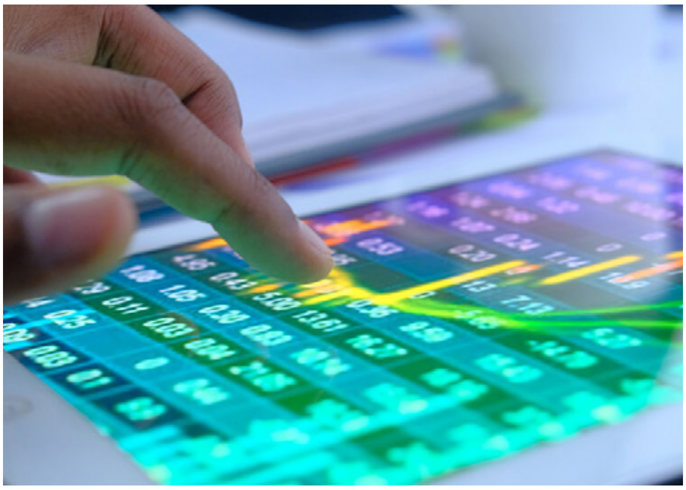
By optimizing the required interest rate swaps, digital annealing decreases the clearinghouse's risk exposure, including the total amount of interest rate exchanged.

Turning to asset management, digital annealing has a significant role to play in **portfolio optimization**, where the ultimate goal is a strong portfolio that is resistant to market fluctuations and delivers steady returns.

Rebalancing a portfolio only periodically results in long periods of reduced earnings, missed market opportunities and exposure to increased volatility and risk in the gaps between reassessments. Digital Annealer provides the capability to do continuous or real-time rebalancing – as the calculations are instant this can be conducted as often as needed – and market fluctuations and risk can be managed more effectively. Ultimately, this has the potential to disrupt whole business processes, enabling lower risk, higher return portfolio management.

continued overleaf...

2. https://www.bankofengland.co.uk/-/media/boe/files/payments/chaps/chaps-quarterly-statistical-report-q2-2018



In terms of long-term optimization, a commonly used technique is to construct a Constrained Minimum Variance portfolio. Correlations between assets are found through clustering, and a tree is created to show an optimized portfolio with low asset correlation and diversified risk. However, creating portfolios that are not easily affected by market fluctuations has been problematic. Clustering provides higher accuracy and larger scale than conventional methods, but in the case of just 500 stocks, the number of possible combinations is 1.63×10^{150}. Hierarchical Risk Parity (HRP) is another technique used on traditional computing systems. However, including more price and volume variables for computation requires extremely high performance and hence HRP on traditional computing does not produce an optimally diversified portfolio providing maximum return with minimum risk.

Fujitsu has also developed a new, proprietary methodology derived from Hierarchical Risk Parity (HRP), called Quantum HRP to provide the highest Sharpe ratio[3] and lowest drawdown.

The range of possible applications for digital annealing in financial services will undoubtedly expand with time and experience. One final example here is in business improvement, where **scheduling management** involves such complex variables that it is currently impractical to generate optimized plans that respond to real-time changes in circumstances.

In a worked example for a Fujitsu customer, an optimized weekly work schedule based on each worker's skills, knowledge, limitations and/or requests, predicted a near 40 percent possible reduction in manpower requirement over the period, as well as replacing the need for time-consuming manual shift allocation.

Other constraints could also be included, for example, the availability of suitably configured RPA (Robotic Process Automation) robots to handle certain workloads. As more and more software robots are deployed to automate simple, repetitive tasks, these can be potentially controlled in real-time by the Digital Annealer, ensuring that the robots are delivering work as efficiently as possible. Given the potential for solving such optimization challenges in real time - running a schedule optimization every hour or minute rather than once a month due to time constraints - what might be the total business impact?

This is where disruption starts.

3. The Sharpe ratio was developed by Nobel laureate William F. Sharpe and is used to help investors understand the return of an investment compared to its risk.

The financial services industry has been one of the first to look towards quantum computing as a possible solution to the complexity and scale of its combinatorial optimization challenges. While true quantum computing solutions to these challenges remain at the experimental level, a new quantum-inspired method of digital annealing has become available and is already delivering radical optimization benefits to early adopters (see page 5).

The possibility has opened up for banks and insurance companies to create a bridge to the quantum future, learning how that new world will look and operate, while delivering real-world optimization calculations that can transform operations and create disruptive leadership in their markets.

Use case:

NatWest bank

Portfolio optimization for agility to respond to the market

Fujitsu is helping NatWest bank solve some of its most complex, challenging and time-consuming financial investment problems by optimizing its mix of high-quality liquid assets (HQLAs) including bonds, cash, and government securities.

Using Fujitsu's quantum-inspired Digital Annealer, NatWest Bank has completed a highly complex calculation that needs to be undertaken regularly by the bank, at 300 times the speed of a traditional computer, whilst providing an even higher degree of accuracy.

Fujitsu worked with NatWest to help portfolio managers optimize the composition of the bank's £120bn HQLAs 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.

In addition to performance improvements, the use of Fujitsu's Digital Annealer also reduces the risk of human error. NatWest can complete a comprehensive risk assessment for its portfolio much faster, as well as, gaining access to a far wider range of results and permutations, therefore helping to ensure an optimized spread and reduced risk.

Financial institutions like NatWest face the continual challenge of creating and maintaining an optimally balanced portfolio of assets, selected from many thousands of options. Ideally, these incorporate a variety of liquid assets that deliver the maximum possible return while helping maintain risk at an acceptable level. While liquidity is of utmost importance to financial institutions, the process involved in calculating the best mix of assets is generally only undertaken infrequently. Traditionally, this is an extremely expensive and time-consuming manual task. The Fujitsu Digital Annealer processes this type of complex scenario and provides results orders of magnitude faster than today's traditional computers.

Given this early success, it is now thought quantum computing power could dramatically change the way many processes are undertaken at NatWest and the bank is now looking at what other portfolios can be calculated using the same technology. For instance, portfolio managers could be able to adjust the allocation of assets following a surprise movement in the market, in a much shorter space of time than normal.

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Web: www.fujitsu.com/DigitalAnnealer