Media Backgrounder Digital Annealer

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While traditional quantum computing is still in a prototype phase and far from any practical application, Digital Annealing is available for use now.

The Fujitsu Quantum-Inspired Computing Digital Annealer is a unique technology that combines the power and speed of quantum computing in a digital circuit architecture to solve complex optimization challenges. It has been described by independent industry analysts as a unique technology offering to pre-empt quantum computing and achieve the benefits of quantum-like solutions, providing performance levels that are generations ahead today, in current data centers. They talk about creating a 'bridge' to the quantum future – taking advantage of the technology's power to solve so-called 'combinatorial optimization' challenges, while also learning how true quantum computing can be applied to future operations.

What is combinatorial optimization?

There is a widespread real-world demand for the ability to choose the optimal solution from a finite set of possibilities, where the scale is typically measured in quintillions. These challenges are classified as combinatorial optimization problems – essentially finding the best combination from an enormous set of potential elements. Example use cases include portfolio optimization and credit risk assessment in financial services; job shop scheduling, car design optimization, robot positioning optimization and many more in manufacturing; drug and materials discovery in life sciences and asset allocation for utilities networks. These problems are difficult to solve optimally in real time with existing processors, even with the fastest computers, as the number of combinations increases exponentially as the number of factors taken into consideration is increased to obtain precision.

Traffic route optimization, for example, is a particularly difficult arena. Optimizing five pairs of start and destination points has to consider 10^{100} possible routes, avoiding overlaps between vehicles and avoiding traffic jams. This use case has been investigated by several global automotive vendors for their autonomous cars and mobility platforms, and by governments as a means to reduce transport's carbon footprint and for the betterment of the society.

Conventional computing has challenges solving combinatorial optimization challenges optimally in a practical amount of time and relies on approximations. Quantum computing computes all possible solutions simultaneously. 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 usable in the real world. On the other hand, quantum-inspired computing with the Fujitsu Digital Annealer is available today and delivers optimization calculations with the speed, precision and at a scale that true quantum computing is not able to achieve. For example, the Digital Annealer solution can solve the five pair traffic optimization challenge dealing with 10^{100} possibilities (as outlined above) in one second.

Digital Annealing

Annealing (see '**The annealing analogy**' below) is a probabilistic technique for approximating the overall optimum result of a given function. Until now, in tackling any combinatorial optimization process with annealing, 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 – often more time than was available - while accepting a 'good enough' answer introduced an increasing amount of risk and the need for a security buffer. The more precise the calculation you can achieve, the more cost-efficient the final process will be, leading to less waste.

Quantum annealing solves the speed side of this equation, but it is unlikely to be available for solving real world scenarios or ready for practical enterprise use for at least 10 to 15 years, if at all. 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.

A convenient way to conceptualize the Digital Annealer is as a special accelerator to speed up combinatorial optimizations, which is always likely to be used together with conventional hardware in a hybrid environment. The technology makes it possible to find a sufficiently precise solution without the need to set complicated parameters. It achieves this by incorporating circuits that automatically control parameters based on the results of observations of conditions within the Digital Annealer during its performance. This can often reduce the preparation time involved from about two weeks to less than a day.

Initial applications

All business 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. Using quantum-inspired computing, the Fujitsu Digital Annealer paves the way for much faster, more efficient materials design, drug discovery, investment portfolio optimization, supply chain optimization, and disaster recovery planning. It will also enable the development of new ICT services that support swift and optimal decision-making in such areas as socio-economic policies and business, which involve complex intertwined elements.

Among the pioneers already making headway, one world-leading **car manufacturer** has engaged with Fujitsu for a range of optimizations including job-shop scheduling, engineering design and the optimization of robot positioning. In the case of robotic welding in vehicle manufacturing, Digital Annealer is calculating the perfect path for production robots setting out from and returning to their base positions. By calculating the optimal angles for the robots to perform welds, the solution has already increased efficiency significantly. The scale of impact is so great that optimization in this one process could eventually increase production vehicle volume in lesser time.

In financial services, Fujitsu has worked with UK bank NatWest to optimize the selection of securities in its £120 billion High-Quality Liquid Asset (HQLA) investment 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. 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.

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.

In the **utilities sector**, one of the most capital-intensive industries in the world, operators must invest billions in new infrastructure, sometimes years in advance of revenue flows. Maximizing profit requires pinpointing exactly where the greatest rewards on early investment in new infrastructure can be reaped.

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.

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 addressing 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, enabling governments to focus their spending on other vital policy areas. More efficient journeys will reduce frustration and encourage economic growth.

Digital Annealer's ability to perform successive, real-time calculations on unbelievably complex challenges stands head and shoulders above today's computers. 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.

Services available in the cloud or on-premises

Fujitsu Digital Annealer is available now as a cloud service, allowing customers to connect with hardware and middleware through APIs. In addition, in order to fulfill applications requiring high frequency usage, Fujitsu is also planning to make on-premises Digital Annealer products available to be installed in customers' data centers.

Fujitsu has also launched the Fujitsu Digital Annealer Technical Service, to support the application development for customers to define issues, as well as build and utilize mathematical models. This support includes:

- Formulation verification - verifying whether the customer's problem can be formulated in a way solvable by Digital Annealer
- Introduction support – a customer-specific proof of concept (PoC) support service, including the definition of all requirements from initial idea to required processes, as well as the mathematical modeling required for an effective execution
- Application construction - construction of the customer system in the form of an application that connects to Digital Annealer services
- Operation – support and quality assurance of the running system, including problem solving.

Large scale performance, high flexibility, fast preparation time

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. The Digital Annealer solution today supports an 8,192-bit fully connected architecture with a promising roadmap to support a 1 million-bit scale solution. This ground-breaking solution is inspired by the key characteristics of quantum computing, 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, and fits into a standard data center rack – or can be run in the cloud – without needing any specific expertise or a complex infrastructure to function.

Fujitsu has also co-created the Digital Annealer 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 prototype true quantum annealing computers, meaning that today's Digital Annealer solutions are guaranteed to be compatible with quantum computers, when these eventually emerge.

Because it is available now, Digital Annealer creates a practical bridge to the future world of true quantum computing, whenever that arrives. When it comes to performance, Fujitsu Digital Annealer is:

- Up to 10,000 times faster than industry standard computing[1]
- 12 Moore's Law generations ahead of current processors
- Data-center room temperature compliant – avoiding the very high energy and complexity costs of advanced cooling systems needed for quantum computers
- On a roadmap to handle 1 million-bit optimization calculations.

With the Digital Annealer, users will be able to find an optimal solution with high probability without setting complex parameters in advance. For molecular similarity comparison problems of below 50 atoms (chemistry), and a portfolio optimization problem for 500 stocks (finance), Fujitsu's Digital Annealer technology was able to shorten the preparation period required to find an appropriately precise solution in less than a day, compared to the previous requirement of approximately two weeks.

The annealing analogy

Annealing methods can be compared with a process in which a metal is heated to a high temperature, and then allowed to cool very gradually, causing the crystalline structure of the material to converge on an optimal state. By lowering the temperature, which in this example is controlled by the parameters, from a high point very gradually, the area in which to look for a solution is gradually narrowed down, finding the point of lowest energy. To rapidly locate this state, one can achieve an optimal degree of precision in the solution if the parameters are operated in a similar way to the gradual lowering of the temperature, but this increases computation time, whereas if the parameters are operated in a similar way to quickly lowering the temperature, the computation time becomes shorter, but the precision of the solution decreases, creating a tradeoff.

The optimal values for the setting of these parameters, including both the initial values and the way they are changed during operation, varies for each type of problem for which these methods are applied. When using annealing methods for problems for which they've never been applied before for the first time, such as comparing molecular similarity and portfolio optimization, finding optimal parameter settings to begin with for each type of problem enables rapid computation for problems of that type thereafter. However, in order to find the optimal parameter

settings to find a sufficiently precise solution in a short timeframe, annealing computation that changes the parameter settings could need to be repeated tens of thousands of times or more which could take a few weeks.

With Digital Annealer technology, the multiple basic circuits that handle optimization processing can be given simple initial parameters and operated in parallel. Moreover, status control circuits installed outside the basic circuits will observe the status during performance of each basic circuit at a set frequency, enabling an efficient search for an optimal solution by adjusting the parameters as appropriate. The result is that users will be able to find an optimal solution with high probability without setting complex parameters in advance. For this reason, tuning tasks that previously had to be done manually, taking up significant time, have become unnecessary, and users can start operations using actual data, drawing out the full performance of the Digital Annealer in a short period of time, with the capability to shorten preparation times by somewhere between one tenth and one hundredth.

In quantum annealing, the practical difficulties of avoiding acceptance of local, rather than global minima in annealing computations is largely overcome by quantum tunneling. Because of this attribute, the system can tunnel through every finite barrier without having to go to a higher energy. This is because the ground state (the lowest level for whatever function is being investigated) exerts the strongest attraction. Therefore, quantum annealing finds the global minimum more quickly and solves the optimization problem.

Both quantum annealing and digital annealing benefit from the accelerated calculation of combinatorial optimizations due to the effects of quantum tunneling. However, quantum annealing suffers from limitations in solving large scale problems due to the limited number of connections between qubits. Fujitsu's Digital Annealer architecture, on the other hand, uses a digital circuit design inspired by quantum phenomena but with a fully connected architecture enabling the free exchange of signals between any two bits. It can therefore solve large-scale combinatorial optimization problems very quickly and – hugely important – more accurately than quantum annealing with its limited qubit connections.

[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.

Online resources

- Video: "Solving Combinatorial Optimization Problems" - https://youtu.be/6Av0pdP2UVA
- Video: "What is Quantum-inspired Computing?" - https://youtu.be/n4ao6MpuYWM
- Fujitsu Digital Annealer Revolutionizes Problem Solving with Quantum Acceleration (press release, March 7, 2019)
  https://www.fujitsu.com/emeia/about/resources/news/press-releases/2019/emeai-20190307-fujitsu-digital-annealer-revolutionizes.html
- Digital Annealer
  Fujitsu Technology Facilitates Application of Combinatorial Optimization Methods to Real-World Problems (press release, September 20, 2017)
  http://www.fujitsu.com/global/about/resources/news/press-releases/2017/0920-03.html
- Digital Annealer Cloud Service and Technical Service
  Fujitsu Quantum-Inspired Digital Annealer Cloud Service to Rapidly Resolve Combinatorial Optimization Problems
  http://www.fujitsu.com/global/about/resources/news/press-releases/2018/0515-01.html
- Digital Annealer
  Fujitsu Laboratories Develops New Architecture that Rivals Quantum Computers in Utility (press release, October 20, 2016)
  http://www.fujitsu.com/global/about/resources/news/press-releases/2016/1020-02.html
- 1QB Information Technologies Inc.
  Fujitsu Laboratories and 1Qbit began collaborations in the AI field, including combinatorial optimization and machine learning, in May 2017. Fujitsu and 1QBit Collaborate on Quantum Inspired AI Cloud Service (press release, May 16, 2017)
  http://www.fujitsu.com/global/about/resources/news/press-releases/2017/0516-03.html

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About Fujitsu EMEIA

Fujitsu promotes a Human Centric Intelligent Society, in which innovation is driven by the integration of people, information and infrastructure. In the Europe, Middle East, India and Africa region (EMEIA), our 28,000-strong workforce is committed to Digital Co-creation, blending business expertise with digital technology and creating new value with ecosystem partners and customers. We enable our customers to digitally transform with connected technology services, focused on Artificial Intelligence, the Internet of Things, and Cloud - all underpinned by Security. For more information, please visit http://www.fujitsu.com/fts/about/