Quantum computing in finance

Quantum readiness for commercial deployment and applications

NTT contact details

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Preface

Our changing world is both a challenge and an opportunity for today's businesses. Especially institutions in the financial sector, who are confronted with growing complexity and less predictability, enforcing the need to use existing data to gain deeper insights. But evaluating scenarios with a broader view and identifying key risk factors within those complex tasks quickly reaches computational limits. In fact, many problems are beyond the reach of classical computers. Quantum technology is a way to provide new paradigms of information processing. New computational models enable ways of evaluating risks more efficiently, gain revenues due to better market positions and automate processes that reduce costs.

In general, quantitative and computational finance apply mathematical and computer science methods to realize financial models or systems. There are several different algorithms and applications, ranging from the analysis of different types of financial risk to optimization methods used in capital markets and insurance. Energy markets can be compared with financial markets in some sense. Computationally intensive models are required to derive and estimate energy prices, predict the deployment of power plants, and calculate short- and long-term costs. Due to changing climate conditions, it's crucial to deploy more renewable resources in our energy grid. But this implies the challenge of matching demand, also in times of low wind and no sun. The optimal composition of power plants, including electric mobility or hydrogen as potential energy storage, forms a potent field of application and combines optimization and simulation aspects. Present models on classical computers can often gain efficiency by adding more CPUs or solve specific tasks on special-purpose hardware like GPUs. At a certain point, that problem can't be solved anymore within the required time to solution.

One solution is to base next-generation computational power on entirely new paradigms: Quantum technologies, in particular quantum computers, are currently the most promising approach to calculate solutions beyond the capabilities of any classical computer – the so-called quantum advantage. To fully exploit the potential of this new technology quantum computers need to be securely hosted as they deliver critical insights. The following whitepaper reflects applications in finance in the context of both quantum software as well as quantum hardware. It evaluates the technical needs quantum technology places on data centers and discusses the benefits colocation data centers offer in terms of stability and security. These use cases only serve as examples of what could be possible. Detailed assessments of developed algorithms and complexity benchmarks are crucial to evaluate requirements for hardware and to derive real business cases (cost versus benefit analysis).

The strategically most promising starting point for this evaluation is to combine experts from different fields. The alliance formed, consists of the quantum computing company JoS QUANTUM, the experienced IT service integrator SVA, the innovative and scalable quantum computer 'managed service provider' AQT, and NTT with expertise in data center infrastructure and connectivity.

> Quantum technology is a way to provide new paradigms of **information processing in quantitative and computational finance** to realize improved financial models or systems.

Introduction to quantum computing

Envisioned in the 1980s by physicists like Richard Feynman and Paul Benioff, the idea of quantum computing has been around for almost forty years. Only recently, due to new developments in hardware manufacturing and failed market expectations of classical semiconductor technology, has the field gained traction and become one of the major emerging technologies of the 21st century. Based on the principles of quantum mechanics it describes a new way of thinking about computation and information in general.

Why quantum computing?

Quantum computing, on the most fundamental level, can be described as the processing of information using the principles of quantum mechanics. Developed at the beginning of the 20th century by some of the greatest scientists of all time, the theory of quantum mechanics has become the foundation for modern technology. Examples range from medical tools like Magnetic Resonance Imaging (MRI/MRT) to everyday-life tools like Light Emitting Diodes (LED). Since these technologies are based on collective quantum phenomena, they are called first-generation quantum technologies. In contrast, the next generation of quantum technologies, just like quantum computing, is based on individual quantum phenomena.

What is quantum computing?

The theory of quantum mechanics describes the world on microscopic scales like atoms and molecules. In contrast to the macroscopic scales that we – humans – typically experience, different laws of physics determine the actions and interactions in this realm. Several physical concepts – most importantly superposition, measurement, and entanglement – describe the physics of the microworld and we briefly touch them in the next paragraphs.

The basic building block for a quantum computer is the quantum analogon to the classical bit which is called qubit. As with the classical bit, the qubit is used to store information and has two distinct states called basis states, typically labelled zero and one. But in contrast to the classical bit, the qubit can also access non-classical states. These so-called superpositions are a mixture of the two basis states. This means the qubit is partly in the zero and partly in the one state, and therefore in both states simultaneously. When using more than one qubit, each single basis state describes the entire qubit assembly, which results in the number of basis states growing exponentially. This gives rise to an exponential space of encoding possibilities for information.

To extract the classical information, a specific action called measurement is done. As part of this measurement process, one of the two distinct basis states is realized randomly. In quantum physics terminology, the measurement is a projection of the qubits to a classical bit register. Even though the measurement is an inherently random process, the probability for each outcome is determined by the state's share in the superposition.

As in classical computation, the interaction and modification of information is done by so-called gates. The computational model is called the quantum gate model with the collection of qubits and gates called a quantum circuit. In contrast to classical computation, quantum gates are reversible. Classical gates can take two inputs and produce a single output. In quantum computation, this isn't possible anymore since information can't be lost on this microscopic level. Therefore, each gate has the same number of inputs as outputs which makes quantum computing highly energy- efficient. Gates can either act on individual qubits or a collection of qubits. In the case of an individual qubit, the state of the qubit is changed, changing the superposition of the two basis states. If a special set of gates is acting on more than one qubit, they can no more be seen as indiviual but as unified. Such gates are called entangling.

In summary, quantum computing can be described as consisting of three important parts. First, the encoding of classical information in the qubits. Second, the modification or computation of this information with quantum gates. Finally, the extraction of classical information by the measurement process. This leaves us with the question of which applications might benefit from using a quantum computer.

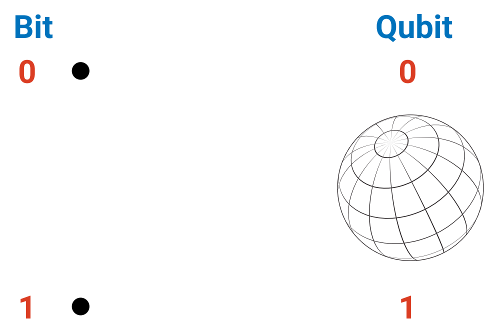


Figure 1: Comparison of bit and qubit: Whereas the classical bit can only access the states 0 and 1, the qubit can also access states that are a superposition of the latter two.

What can we do with it?

Only about ten years after exchanging ideas for quantum computation, the first algorithm with a proven advantage compared to classical algorithms was discovered. It was designed at AT&T Bell Labs by Peter Shor and can be used to factor large integer numbers. At first glance, this looks like a result only interesting for didactical purposes. But the problem of factorization, or more precisely, the problem of calculating discrete logarithms is the basic framework for modern-day asymmetric key cryptography. Though, algorithms of this type typically require a rather large number of error-free qubits, so-called logical qubits (see Info-Box: Quantum error correction).

As of today, quantum computers only approach qubit-numbers in the order of a hundred, so quantum error-correction can't be used. However, new algorithms have been developed that are based on the interplay of classical and quantum computers and are therefore called hybrid. In these algorithms, the quantum computer is typically used to explore and describe the classically not accessible solution space while the classical computer is used to optimize this exploration. We'll address hybrid architectures in more detail in the following sections.

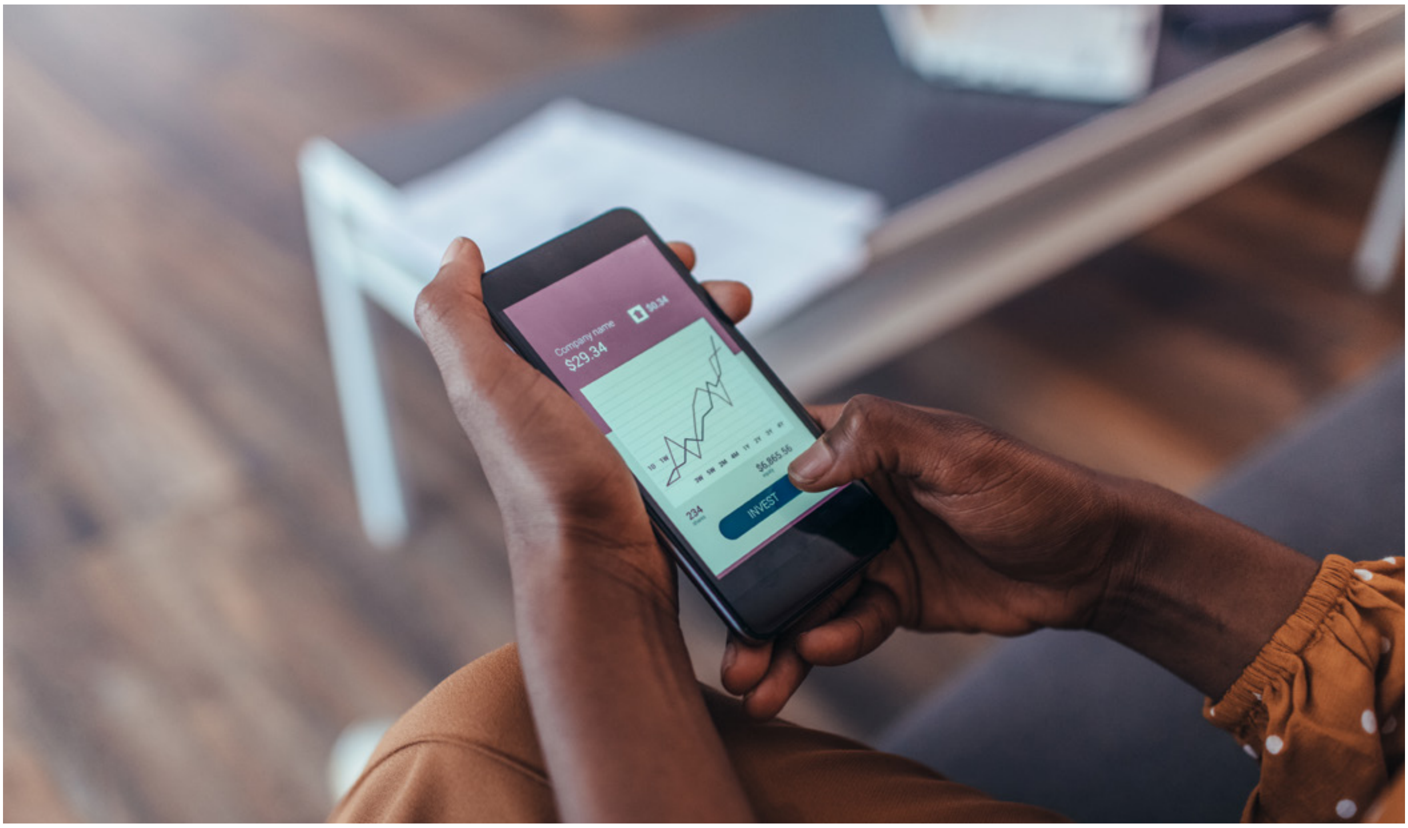
More generally, current quantum computers should be seen as tools that can be used to accelerate specific types of workloads. Therefore, quantum computers will coexist with classical computers.

However, the past showed that continuous improvement and the invention of new methods lead to developments. Once error mitigation and error correction protocols will step in place, the full power of quantum algorithms will be released. First experiments already show the working principle of quantum error correction schemes and the possibility to run algorithms on logical qubits.

> If a special set of gates is acting on more than one qubit, they can **no more be seen as indiviual but as unified.** Such gates are called entangling'

Quantum error correction

Similar to classical bits, qubits are sensitive to external influences and, as a result, are prone to errors. Therefore, error-correction techniques have been developed that use a level of redundancy to store information in an error-free or error-correcting manner. Such redundant operation is achieved by aggregating a number of physical qubits (present in the hardware) into so-called logical qubits. A disadvantage of error-correction techniques is the increased execution time and the high number of required physical qubits.



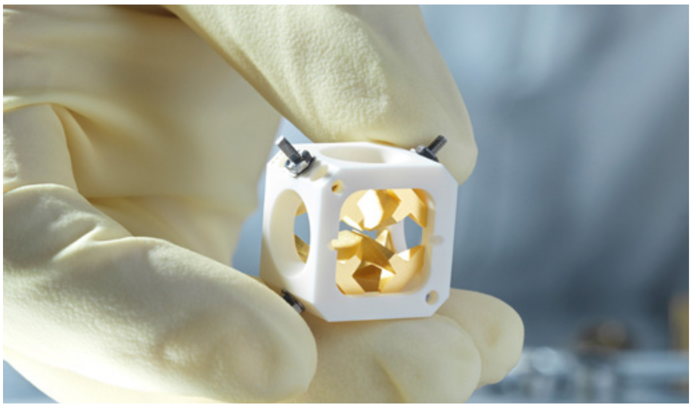
How does quantum hardware work?

The main challenge in realizing a quantum computer for industrial applications is designing and building a system that is large, fast, and accurate enough to solve problems that are intractable with classical resources. The focus here is on, enough, because for large-scale problems even a small decrease in execution time or slightly better accuracy of the result can lead to a significant business advantage. Several competing quantum hardware paradigms address these issues, ranging from superconducting and photonic circuits to ultracold atom arrays and trapped-ion platforms (see table below: Different qubit technologies). Each platform has its specific properties that might be advantageous or hindering to the task at hand. However, all those quantum computing technologies have one thing in common – they're still in the early development stages and there's no single technology that's suited for every task yet. But as can be seen later, some technologies have already made their way into production usage.

Different qubit technologies

Technology	Type of qubit	Advantages	Disadvantages
Neutral atoms	Energy or spin states of neutral atoms held in an optical lattice	Close-to-homogenous qubits, excellent connectivity, room temperature	Requires sophisticated control technology
Photonics	Polarization, time, or position of photons in optical waveguides	Fast operation, scalable fabrication, room temperature	Heterogenous qubits, limited connectivity, lack of key components (single photon sources and detectors)
Quantum dots	Energy or charge states of individual electron spins of solid-state nanostructures	Well established and scalable fabrication using lithography	Heterogenous qubits, limited connectivity, cryogenic temperatures
Solid-state spins	Energy or spin states of individual defects in doped solid-state materials	Insensitive to operation environment, room temperature	Heterogeneous qubits, hard to manufacture in a controllable fashion
Superconductors	Magnetic flux of charge states of superconducting Josephson junctions	Well established and scalable fabrication using lithography	Heterogenous qubits, limited connectivity, cryogenic temperatures
Trapped Ions	Energy or spin states of charged atoms held in electromagnetic fields	Homogenous qubits, excellent connectivity, room temperature	Requires sophisticated control technology

Any quantum computing system in itself is a hybrid classical-quantum device, in which basic elements of quantum technology are interfaced with classical control and logic. Generally, they consists of two main parts: hardware stack and software stack. Common building blocks within each quantum computing stack are shown in Figure 2. The stack covers fundamental technology, such as the type of the qubit and addressing technology, on the bottom, and the quantum algorithms and applications on the top (for more details, see, for example, Ref.[1]). Tight and efficient integration not only vertically, but also horizontally across the entire stack is nowadays one of the main tasks for research and development teams in quantum computing.



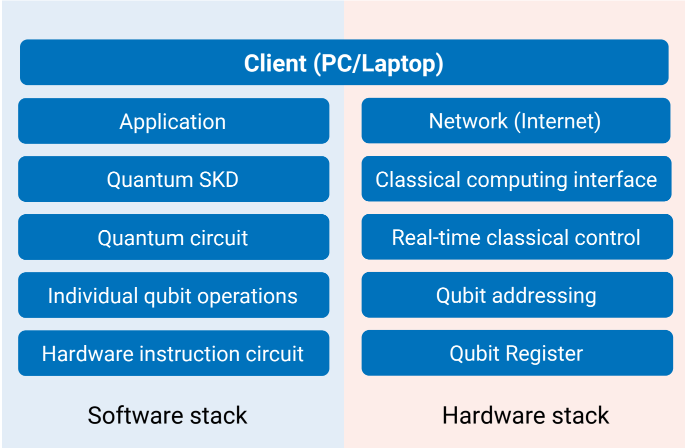


Figure 2. Quantum computing stack. In general, individual hardware and software modules can be interconnected on a local level (interconnects not shown

Current state-of-the-art devices seamlessly integrate quantum hardware with quantum programming software frameworks, keeping most of the complex underlying individual quantum hardware implementations hidden 'under the hood'. Typically, access is provided via public or private cloud offerings and the quantum computers can be programmed from a laptop (read more about it in the 'How to get started' section). But there are important distinctions between different technologies that can critically impact the final outcome of quantum computation. For example, the same quantum algorithm can lead to dramatically different outcomes if transpired for the wrong qubit platform. Although reusing the same code on different quantum hardware might seem easy at first sight, the quantum programmer still needs to be aware of the specific quantum hardware the code has been written for. Qubit connectivity, error-correction techniques, and supported basic qubit operations can be very different. At present, the final performance of a piece of quantum code is still determined not only by the hardware it's executed on but to a large degree also by the developer's ingenuity and sophistication.

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Quantum performance indicators

Qubit number: The number of qubits gives a rough estimate for the amount of quantum information that a quantum processor might be able to operate with. More precisely, it describes the number of physical qubits in the quantum register that one can use for calculations.

Qubit connectivity: The ability to perform a basic quantum operation between any two qubits from the quantum register. For example, in ion-trap based qubits, a quantum gate can be executed between any pair of qubits – in this case, all qubits are 'connected', or, in other words, it's 'all-to-all' connectivity. In contrast, in superconducting circuits only gates between neighbouring qubits are technologically possible – the connectivity is limited. While it's still possible to perform logical gates on qubits that are located at physically different locations on a superconducting chip, it significantly increases the computational overhead in terms of operation speed, quality, and code length.

Gate fidelity: Besides different qubit connectivity, current qubit operations are prone to errors, which must be considered when programming any quantum algorithm. Such error performance of a specific implementation is characterized by its 'gate fidelity'. This describes the quality with which individual quantum operations will be performed by the given quantum processor. Higher gate fidelity means fewer errors during the algorithm execution. Trapped-ion processors have been at the forefront of gate fidelity records, with common fidelity greater than 99%.

1 Rodney Van Meter and Clare Horsman, A Blueprint for Building a Quantum Computer, Communications of the ACM, October 2013, https://doi.org/10.1145/2494568

Road to applications

As discussed earlier, the first applications for quantum computers will be based on hybrid algorithms. As a result, they will use the interplay of classical and quantum computers. However, quantum computers that will allow for quantum error-correction emerge at the horizon aiming for more advanced algorithms and applications.

The known quantum algorithms are based on Shor's and Grover's algorithm. Shor's algorithm is a quantum algorithm that can be used for factoring integers and computing discrete logarithms in polynomial time. It was the first quantum algorithm that achieved an exponential speedup over classical algorithms. The later one can be applied to a broad variety of search problems and shows a quadratic speedup compared to naive classical methods. Generalizations of this algorithm can be applied to simulation, search, and optimization. As these algorithms require a huge number of qubits and gates to outperform classical algorithms in production size, error-correction is required to get valid calculations.

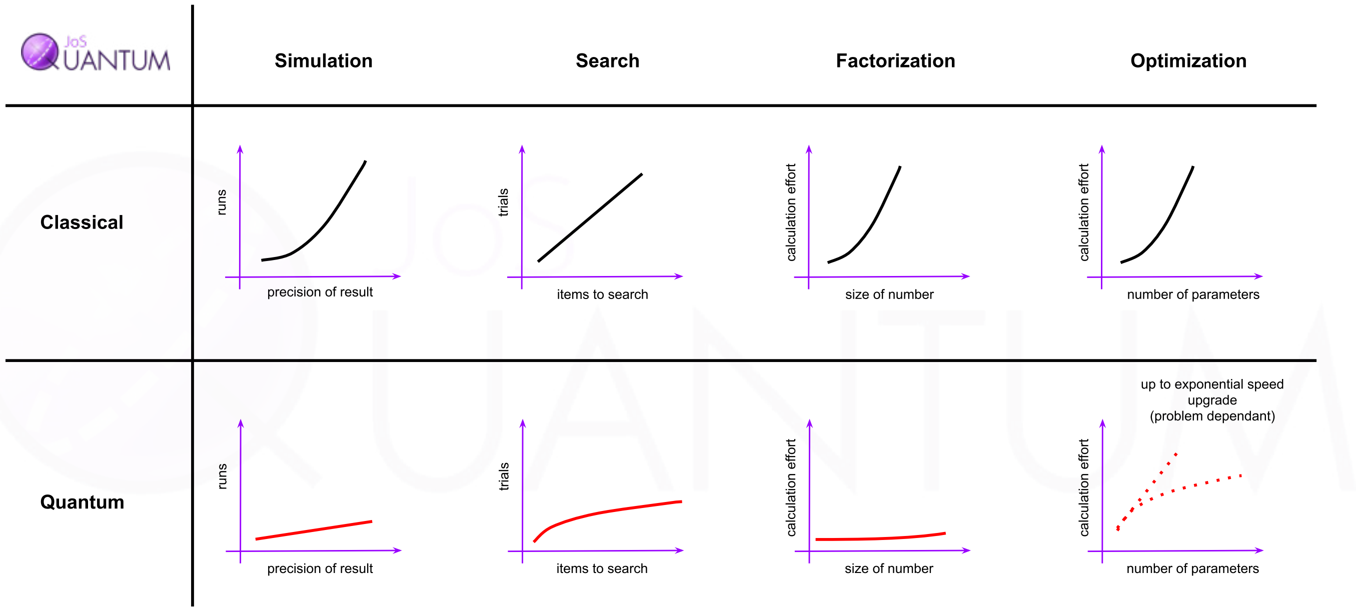


Figure 3. Performance scaling of quantum versus classical algorithms for generic classes of use cases. This shows the very abstract view of the complexity and may vary for specific problem classes

Other classes of algorithms try to make use of the currently available machines, as with current quantum hardware it's not possible to execute quantum algorithms with thousands of gates without returning noise. These types of algorithms were introduced recently that make use of so-called Noisy Intermediate-Scale Quantum ('NISQ') computers. These machines will allow the execution of relatively short algorithms with low numbers of gates and qubits. The applied quantum algorithms estimate eigenvalues of operators and tolerate a certain level of errors. They can be used in quantum chemistry to calculate molecular structures and extensions can be used to find solutions in combinatorial optimization where problem space grows exponentially. Although quantum heuristics may provide better solutions in a shorter time frame, complexity comparisons aren't possible in a general manner. Complexity comparisons need to be taken for specific use cases and applications.

Even though quantum computing is still in its infancy, this is the right time to set the course for production use. There are two key points to address: On the one hand, it's essential to identify and develop use case scenarios. On the other hand, efficiently using development environments and transforming them into production environments are key to success. Efficient functions and routines including compilers and resource management that can use classical and quantum hardware will become very important in a production environment.

How to use quantum computing in finance?

To show possible areas of commitment, this section shortly describes possible use cases and applications delivering real business value in finance.

Portfolio optimization and asset allocation

Investment decisions are largely based on allocating budget to various assets and asset classes aiming to realize a desired return on investment while minimizing certain risks. This is known in modern portfolio theory as Markowitz optimization. When deciding whether to build up long or short positions of individual assets or asset values under the constraint of a capped investment sum, a combinatorial optimization problem arises which can't be solved efficiently by analytical methods.

Therefore, heuristics have been developed that try to obtain solutions using approximation methods. But even those fall short in terms of runtime and solution quality. This means that they typically require hours of runtime and still don't find optimal solutions. Furthermore, if additional constraints like transaction costs or restrictions in the investment volume per asset are introduced, modern heuristics no longer find a good solution, run forever or get trapped in local optima.

State-of-the-art approaches try to include additional stochastic parameters like interest rates, different economic scenarios or uncertainties in input parameters in general, which can be referred to as robust optimization. Additionally, if input parameters depend on each other, scenario-based techniques can be introduced and explicitly considered in the optimization process, to include different macro-economic and political developments.

Services based on quantum algorithms could produce better results, produce solutions in less time or take more constraints into account. Risk-management could start from backward-looking models towards forward-looking models as stress tests can already be considered within the asset allocation process.

Risk management and Monte Carlo simulation

Monte Carlo simulations are used in many different ways. A prominent example is the valuation (of risks) of financial instruments. Several typical scenarios (hundreds of thousands) are generated, the corresponding pay-outs/risks are calculated. Finally, an expectation value or a risk measure such as value-at-risk is determined.

The realization of Monte Carlo-like simulation on quantum computers is already possible for small demonstration purposes. Quantum properties can be used for both, generating random paths/scenarios and evaluating expectation values. The paths (scenarios) are encoded in the qubits. Their collective state is used to resemble the (probability-weighted) pay-out function. With n qubits, 2n paths can be realized. The expectation value can then be determined by a quantum algorithm that offers a quadratic speedup compared to classical Monte Carlo methods. To extend this algorithm to realistic use cases, a higher number of qubits is needed to allow for a higher resolution.

Synthetic data generation

With the intensified use of artificial intelligence and its need to create anonymous training data, synthetic data generation is gaining importance every day. Creating such synthetic data is the core of a generative adversarial network. It consists of two neural networks, a generator and a discriminator that try to outcompete each other. The generator creates a sample of synthetic data based on a given number of input parameters to deceive the discriminator. The discriminator tries to distinguish this synthetic data from real training data. If both parties are trained well, the generated data is so perfect that it can't be distinguished from the real data by the discriminator. This structure allows for an extremely promising training process, whereby various processes can be replaced and extended by quantum algorithms.

An exponential advantage over classical networks can be achieved by generating data from samples of measurements in high-dimensional spaces. By using quantum computers, correlations can easily be taken into account resulting in decisive advantages in terms of the risk analysis of the financial infrastructure, the portfolio of insurance companies, the detection of fraud and terrorist financing, and the stability of energy networks. Additionally, generative models could also be used to efficiently load distribution functions into quantum computers in order to perform operations on the represented data (e.g., determining risk measures such as value-at-risk or expected shortfall). Other applications involve generating synthetic market data that represent realistic developments at the individual value level and macroeconomic trends and shocks. This would enable forward-looking risk management since it wouldn't be necessary to test and train on old known data (back-testing) but on new realistic scenarios. This would enable exchange operators and clearing houses as well as regulators to create realistic stress tests paving the way to forward-looking risk management.

An exponential advantage over classical networks can be achieved by generating data from **samples of measurements in high-dimensional spaces.**

How to get started

The key to develop quantum-enhanced applications is to tailor use cases – respectively algorithms – to financial situations with real data. Since programming quantum computers is so fundamentally different from programming classical computers, new intuition and development skills need to be learned and acquired. More precisely, by creating interdisciplinary teams of domain specialists and quantum specialists, expertise can be built to understand and transform the specific use cases into an application. A good starting point can be a workshop that is used to identify interesting use cases.

Fortunately, there are already a number of available frameworks providing different functionality for quantum computing. For development purposes, the programming language Python with packages like Cirq[2] or Qiskit[3] has become dominating. Most importantly, the frameworks offer a high-level description of the underlying computation, allow to compose small scale circuits, and learn about quantum algorithms. As most of the frameworks are developed as open-source software (Apache License 2.0), providing access to privately-managed hardware resources is easily possible.

To prevent the leakage of acquired intellectual property and protect sensitive data, it's necessary to use a private cloud development infrastructure located in Europe. This infrastructure provides access to the quantum hardware, located in the same data center, and a platform for collaborative development. The core of this collaboration platform is an interactive browser-based development tool allowing for collaborative development, simulation of circuits, and production use case development. As circuits are first tested on a small scale, powerful simulators are necessary which can be extended by hardware emulators to consider noise. Later on, quantum circuits can be executed on real hardware in a data safe environment. Furthermore, access to classical high-performance simulators is given.

After developing use case scenarios and implementing proof-of-concept like technology demonstrators, the question of production environments typically arises. On the road to production usage of quantum computing in business, operational and regulatory requirements need to be considered.

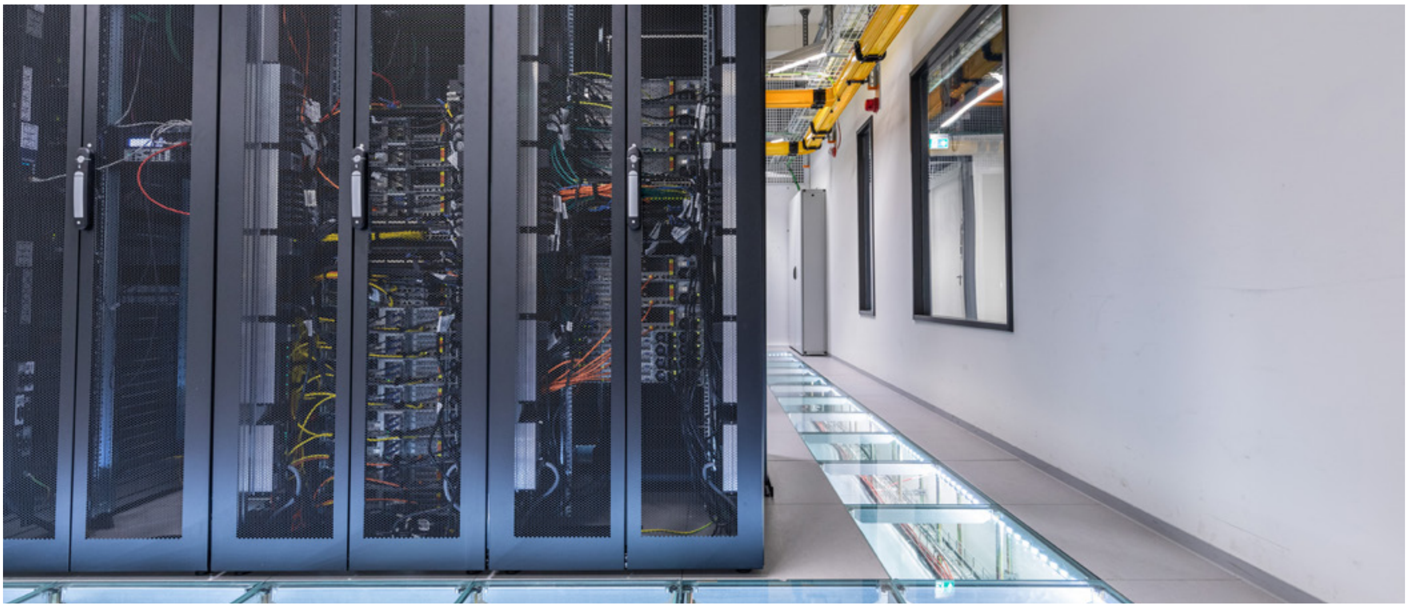
In current frameworks so-called quantum assembly languages (e.g., QASM[4]) are used to translate high-level Python code to assembly instructions for quantum hardware. Pre- and post-processing routines need to be implemented as well to manipulate input, model and gate parameters.

Figure 4. Top: ion-trap quantum processing module in a 19-inch rack; Bottom: Photograph of an AQT quantum computer system

2 *cirq.readthedocs.io/en/stable/*

3 *qiskit.org/*

4 *github.com/QISKit/openqasm*



Superconducting devices, spinning atoms, polarized photons, quantum dots, and trapped ions – there are different qubit technologies quantum computers can be based on. Among them, ion-trap computers offer several advantages. They provide high performance and reliability, enable on-demand access and meet industry standards. AQT has a lot of experience in developing quantum computers through access to decades-long operation within the experimental physics groups at University of Innsbruck, from which it was spun out.

The technology that AQT has developed simplifies use, installation, and maintenance, and therefore minimizes the required ownership resources of a quantum computer. In the following list, the main specifications of the systems are briefly explained:

- **Size:** All components (see the section on How does quantum hardware work) are engineered to fit within 19-inch rack cabinets, familiar to existing HPC infrastructure and data center installations. The entire quantum computer requires only two full custom racks, with a floor space usage of less than 4m^2.
- **Power consumption:** The overall power consumption of a single quantum computing system is less than 3kW and won't rise above this value with increased computing demand. Not only does this reduce the running costs but the heat produced is significantly lower than classical computing solutions.
- **Operating temperature:** The trapped-ion quantum computer operates at room temperature and is very comfortable within the temperature around 20-25°C.
- **Vibrations:** To ensure the best achievable performance, low-vibration floor space is preferable. However, all AQT quantum computer systems integrate state-of-the-art active vibration insulation to achieve optimal performance under all given circumstances.
- **Connectivity:** Several hybrid quantum-classical optimization solutions can benefit from the close proximity of quantum and classical resources. The quantum hardware can be connected to existing network architecture with a standard 10Gbps SFP+ port and supports standard network protocols for communication.
- **Integration:** To leverage the potential of quantum-enhanced workloads an integration into existing environments is possible. Especially for high-performance computing resources, this can be done by pairing the quantum and classical resources, creating a quantum accelerated computing node. This allows for simple access to the quantum resources and scheduling of workloads.
- **Cooling:** The quantum computers from AQT are all-air cooled and can be installed without expensive or complex cooling systems.
- **Physical access:** To achieve the highest component density and the smallest foot-print, the quantum computing racks have been designed with front and back access, as access from both sides is required during the maintenance. When operated normally, racks remain closed and no opening is required.
- **Maintenance:** A status monitoring system runs in the background that consistently measures and evaluates system performance. Several automatic tune-up routines ensure high system availability and optimal performance. The software can be maintained via both local and remote access. If needed, a qualified technician can perform planned maintenance on hardware components or emergency recovery.
- **Software development frameworks:** The quantum hardware is fully compatible with the largest quantum software programming frameworks, such as, Qiskit, Cirq, Pennylane, and can be programmed 'out-of-the-box'.

Where will it run? - Quantum in the data center

Exploring and using new technology such as quantum computing brings along many chances and challenges as outlined earlier in this whitepaper. Especially, when talking about quantum technology in financial applications there are three main issues to be considered:

Security: Financial institutions deal with extraordinarily sensitive information and the decision of how and where to use a new technology needs to ensure that the high level of security can be kept. In terms of physical security, this implies that the IT infrastructure is hosted on secure grounds well protected against made-made attacks, acts of nature, fire, or power outages.

Compliance: Most financial applications operate under some form of regulatory control. Banks, as well as insurance companies, underlie strict regulatory compliance rules, e.g., FISMA, PCI DSS, ISAE3402, and, in addition, payment providers require IT processes aligned to ISO 27001 BSI. Additionally, GDPR takes an important role in all financial applications. For companies that are subject to such regulations, they must remain compliant and know where their data is at all times. Dedicated audits are conducted on a regular basis to ensure that IT infrastructure and the applied security systems follow the regulations.

Control and access: One of the key aspects of security and compliance is to assure that all data is constantly under the control of the institution and no unauthorized access can take place.

These main issues directly lead to the key questions: How and where should the quantum devices be operated? As they offer completely new ways of how data is computed, the respective hardware architecture is quite different from classical devices. And their requirements towards the environment where a quantum device is supposed to be operated are also slightly different.

Generally, there are two operation models in place, how IT resources can be used:

- Acquire, deploy, operate and maintain a quantum computer on your own or with the help of an integration service provider. This can be either performed in a company-owned and -managed data center, or in a colocation space in a professionally managed data center.
- Use Quantum-as-a-service (QaaS) to source quantum computing power from a provider who owns and operates one or more quantum computers and provides its capabilities via a globally connected and publicly available platform.

On-premises	Off-premises
Acquire, deploy, operate and maintain a quantum computer on your own or with the help of an integration service provider. This can be either performed in a company-owned and -managed data center, or in a colocation space in a professionally managed data center.	Use Quantum-as-a -Service (QaaS) to source quantum computing power from a provider who owns and operates one or more quantum computers and provides its capabilities via a globally connected and publicly available platform.

Taking into account the three key issues – security, compliance, and control – as outlined before, using their own quantum computer on-premises to perform financial applications brings along several advantages. For companies that are subject to regulations and high-security standards, they must remain compliant and know where their data is at all times. Especially with having strong privacy concerns, it’s more likely that companies would prefer to operate systems in a space that they can access at any time. Using an on-premises environment, enterprises retain all their data and are fully in control of what happens to it. Additionally, it needs to be considered that as of today the range of QaaS providers and their offerings are very limited. This leads to the point that organizations – especially when dealing with financial applications – will more likely decide to strategically take operations into their hands.

As soon as the strategic decision to operate their own environment is taken, the right location to host the quantum technology needs to be identified. Colocation data centers as the professionalized on-premises environment are today optimized for the operation of ‘traditional’ IT systems, like servers, storage, and networking. But especially in terms of security and compliance, they offer many advantages that serve quantum technology just the same as traditional IT systems. Also, if one takes into consideration that there is a strong need for hybrid infrastructure this can easily be achieved in a colocation data center.

To make sure a data center is well prepared for the deployment and operation of quantum hardware, several precautionary measures must be taken depending on the platform architecture. As the ion-trap technology is one of the most advanced architectures for commercial use, it will be the basis for the following considerations.

In contrast to other quantum hardware, ion-trap systems can be hosted in 19-inch racks with 47 height units, just as traditional IT-systems. NTT offer either the option to use open colocation space with pre installed 19in racks (width: 600mm or 800mm; depth: 1200mm) or caged areas where the rack format can be chosen individually. Both areas are hosted in a very stable and secure environment ,with low vibrations due to the solid construction and building architecture that is used in all of the 160 data centers located in 20 different countries around the globe.

As already outlined before, the power consumption of quantum computers is far lower than one might assume. Different from traditional computer systems, the power consumption of quantum computers almost stays constant no matter how complex the performed tasks are. A standard temperature of around 23°C and cooling can be achieved with air only instead of water cooling that is essential for supercomputers. Therefore, the use of quantum technology is quite beneficial on a journey towards a sustainable future.

Quantum computers need a standard voltage of 230V/400V at 50Hz. When using an open-colocation space, up to 8kW per rack are available and in caged areas, higher power densities are possible – depending on the number of square meters. The big advantage of NTT's colocation data centers is the high availability of 99,999% offered. Own transformers on the data center campus, redundant UPS and emergency power in each building that can secure operation for up to 72 hours in case of a regional power outage are realized to fulfil Tier-3 standards and ensure business continuity that is essential especially in financial applications. All in all, it shows most of the requirements coming along with quantum technology are therefore quite similar to what has already been established in state-of-the-art data centers, ranging from constant cooling systems with a continuous air flow to 24/7 secured spaces with reliable fire prevention, 7-zone security concept with inhouse-personnel and standardized business continuity processes.

In addition to that, connectivity and room for experimentation play a key role when it comes to deploying quantum technology. Installing quantum computers in a colocation space within an NTT data center simplifies both. Traditional servers and quantum computers will be operated next to each other and every customer has pre-cabled access ports to the passive/neutral building infrastructure, as well as to the Multi-Service Interconnection Platform (MSIP) offering access to all major carriers (350+), internet exchanges, and cloud providers. Public cloud services such as Google Cloud, Amazon Web Services, Microsoft Azure, IBM Cloud, Alibaba AliCloud and Oracle Cloud. can also be directly connected. Initiatives just like the one that has been taken with the partners contributing to this whitepaper are provided with space to experiment.

Conclusion

Quantum computing is neither science fiction nor is it a technology that can only be used by a handful of scientists in their laboratories. The technology is just now entering the world of business. This is the time to explore quantum technology, to assess the potential for future applications. Many companies have already started their journey, acquired strategic knowledge, and secured intellectual property. As a key point, they started the discovery processes to evaluate applications and business cases.

Applications in the financial industry are challenging use cases for quantum technology that need to be addressed in a secure and stable environment with reliable hardware and software. The alliance of AQT, JSQ, SVA and NTT provides cutting-edge, one-stop solutions and services to help explore applications and provide resources. Our capabilities can cover your quantum project from start to finish: consulting, development, deployment, integration, operations, hosting and colocation.

If you're interested in starting your quantum journey today – or in lifting it to the next level – reach out to us and let's have an introductory conversation without any obligations.

Let's get started together!

Contact

Alpine Quantum Technologies GmbH (AQT) – Quantum computing hardware for on-site integration using industry standards

AQT is a quantum computer hardware startup located in Innsbruck. Building on decades of experimental and theoretical expertise in the field of quantum information processing, our goal at AQT is to get quantum technologies out of the laboratory environment and turn them into everyday products. The long-term goal is a quantum computer based on trapped ions, that is installed in normal IT infrastructure and can be readily operated from any PC or laptop.

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JoS QUANTUM (JSQ) – Quantum solutions for capital and energy markets

Founded in 2018 in Frankfurt, Germany, JoS QUANTUM is developing models and algorithms for usage in optimization and simulation with applications in financial and energy markets. Together with innovative workshops and prototyping of relevant use cases, JSQ provides a managed development environment with access to simulators and hardware.

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SVA System Vertrieb Alexander GmbH (SVA) – IT Service Integrator

SVA System Vertrieb Alexander GmbH is one of the leading German system integrators. The corporate objective of SVA is the combination of high-quality IT products of different vendors with the project know-how and flexibility of SVA to achieve optimum solutions for customers. SVA experts combine twenty years of IT infrastructure experience with know-how about modern demands such as data center security 2.0, big data and analytics, workspace of the future, cloud, and agile IT and software development.

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NTT Global Data Centers EMEA GmbH (NTT) – Colocation data center services

The Global Data Centers division of NTT Ltd. designs and operates over high-quality, mission-critical data centers across 600,000 m^2. We understand that every business – large and small – has its own unique needs and goals when it comes to their data center infrastructure. Through our tailored local expertise, our worldwide connected platform and NTT's portfolio of global technology solutions, we are an enabler of growth and innovation for our clients – wherever they are in the world.

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