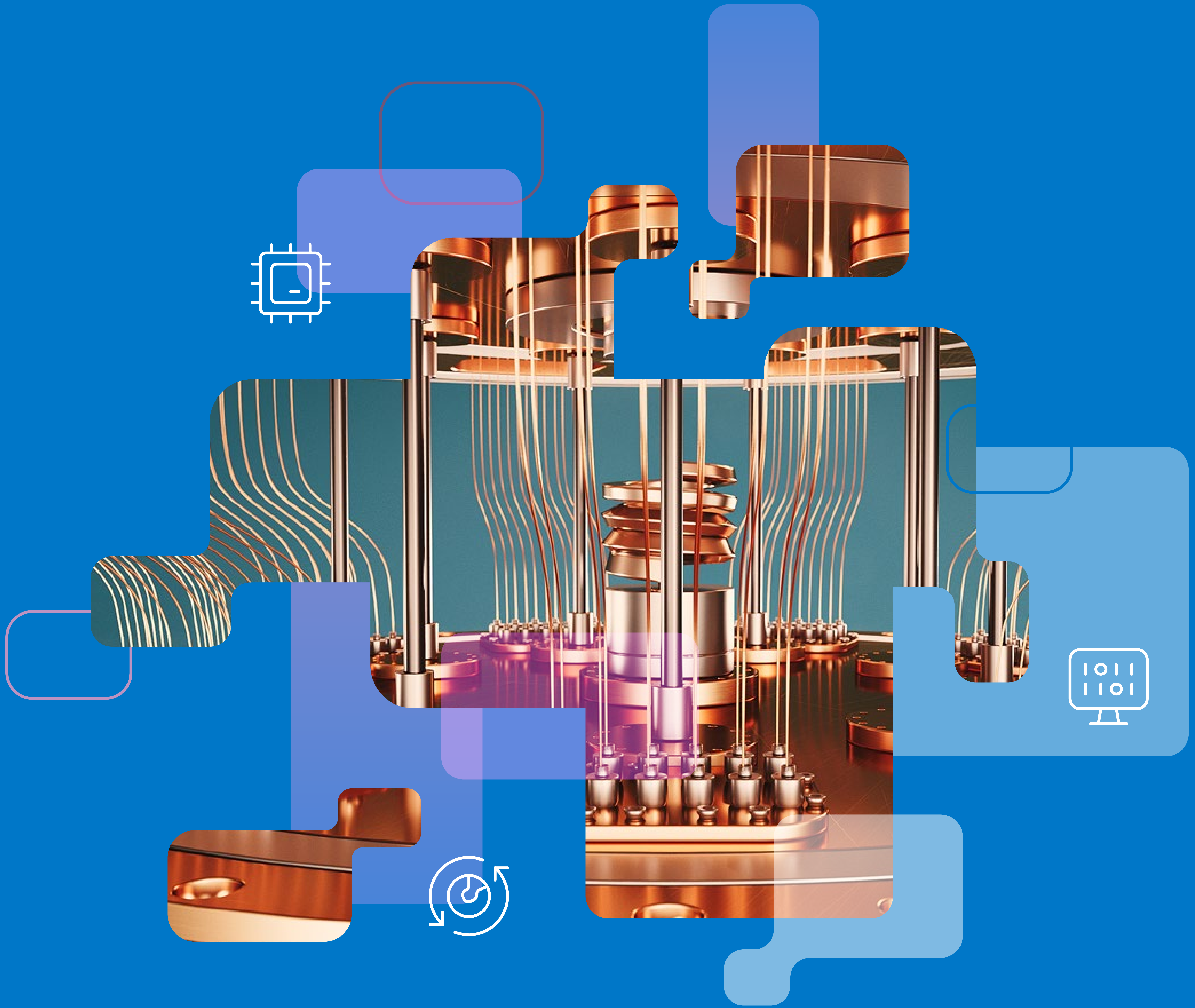
Quantum



- → Quantum Key Distribution (QKD) gaining momentum
- → Quantum Computing in the Cloud
- → Hybrid quantum/classical computing
- → Error correction techniques
- → Quantum curiosity

Quantum Information Science and Technology (QIST)

There are three main subfields under the umbrella of Quantum Information Science and Technology (QIST): quantum computing and simulation, quantum sensing and metrology, and quantum communication. In the Netherlands, these fields are reflected in the Quantum Delta NL catalyst programs. In this section we elaborate on these fields.

1. Quantum Computing

Quantum computers are devices that process information by taking advantage of the quantum-mechanical properties (superposition, entanglement and interference) of their building blocks, the qubits. These qubits harness work in a powerful and efficient way and perform certain operations with an exponential speed. Currently available quantum computers are known as ‘noisy intermediate scale quantum’ (NISQ) devices. They contain small numbers of qubits and suffer from decoherence, meaning that information is altered by the system’s interaction with its environment. NISQ devices can be used to execute quantum algorithms that do not require deep and fully coherent quantum circuits. Generally, these algorithms are executed in a hybrid way: classical and quantum resources are combined to make use of their complementary strengths and features. This results in a more robust and flexible approach than using NISQ devices alone (hybrid quantum/classical computing). Quantum computing dramatically alters the way we solve problems at a fundamental level. To take advantage of quantum computing, it’s not enough to further develop the hardware, we also need to rethink the way we normally approach problems. We have to create and redesign algorithms from the ground up and identify the applications that can benefit from quantum computing.

2. Quantum Sensing

Quantum sensors can measure different physical properties with extreme precision. These properties include temperature, pressure, rotation, and electric and magnetic fields. Their precision stems from the sensitivity of quantum states to minor changes in the environment. Some quantum sensors can measure much smaller quantities than current sensors, while others provide better resolution when images are captured. Due to their high sensitivity, areas such as renewable energy, nuclear energy, and geothermal energy have been adopting quantum sensors for their applications. In the future, quantum sensors could be placed in a quantum network with quantum processors, allowing sensor data to be correlated in the quantum information plane.

3. Quantum Communication

Quantum communication services, such as the delivery of entangled qubit pairs, allow quantum processors, sensors, and computers to exchange quantum information using quantum protocols. Entangled qubit pairs have the quantum mechanical property that a change in properties of one qubit results in a direct change in properties on the other qubit, irrespective of the distance between the qubits. The transmission of quantum information and eventually the communication between quantum computers is also the foundation for a quantum internet (QI): a quantum network with features like the internet we have currently.

A first quantum communication service, that can be implemented today, provides an alternative to conventional encryption of sensitive data. Sensitive data, once encrypted, is sent across fibre-optic network cables and other channels together with digitally computed semi-random keys needed to decode the information. The data and the keys are sent as classical bits—a stream of electrical or optical pulses representing 1s and 0s. That makes them vulnerable, as quantum computers can potentially reverse the algorithm used to compute these keys. Quantum key distribution (QKD, one aspect of quantum communication) allows classical information to be encrypted using truly random key material that cannot be decrypted using classic or quantum computation techniques.

TREND #1

Quantum Key Distribution (QKD) gaining momentum

Public values

Autonomy Privacy

Justice Trustworthiness of information

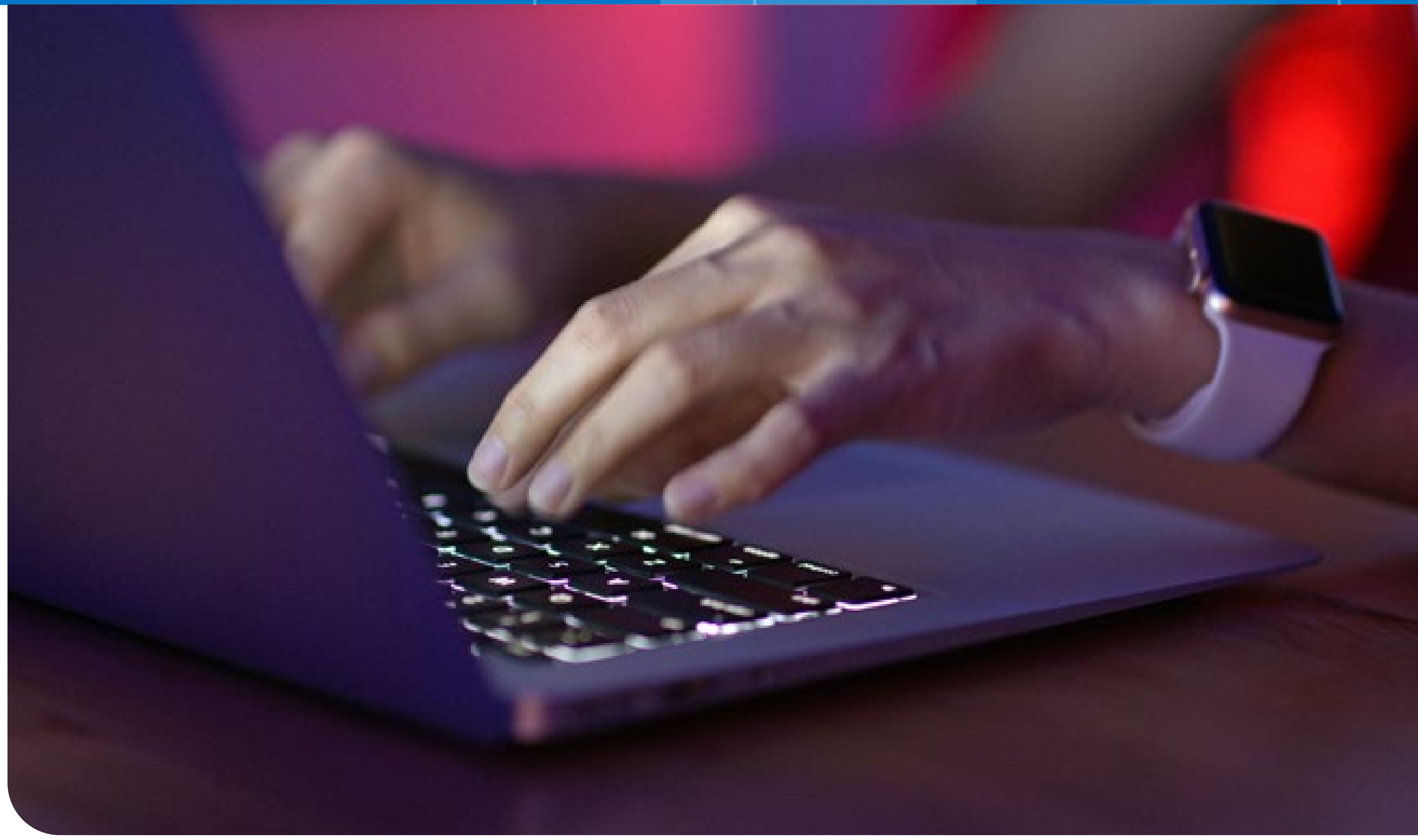
Humanity

Readiness WATCH PLAN ACT

Drivers

#Cyber security #Digital economy #Privacy #Research environment

QKD is a secure communication method that enables two parties to produce a shared random secret key known only to them, which can then be used to encrypt and decrypt messages. As opposed to classical key distribution, QKD allows users to know when a third party is attempting to gain knowledge of their key. QKD is not new, some companies have already taken advantage of it. But it is only recently that QKD equipment is becoming commercially available; currently seven companies worldwide are offering commercial QKD systems. Additionally, integration is becoming easier: European and International standardization bodies (ETSI and ITU) have standardized interfaces allowing connections between QKD equipment and other equipment and software packages.



Quantum Key Distribution: The Future Of Secure Communication

The European Commission has launched several calls to implement a quantum communication infrastructure with tooling for full funding when co-funded nationally.

open example

Quantum Cryptography Market

Market research shows us that the global quantum cryptography market is growing at a compelling rate. In 2031, the market is expected to be eight times larger than today.

open example

IMPACT

QKD is still expensive to implement for any large-scale educational service/purpose. First use-cases will be in high-security scenario's, such as transport of medical data The technology will probably not be used in education, but it will trigger the need to develop - through establishing curricula - competence for operating and building equipment. The technology will have an indirect impact on research. With the use of QKD, research data can be encrypted on different layers in the network. In addition, QKD will create active research in finding and implementing more robust protocols and in the technology needed to make these protocols work over ever greater distances. This impacts research on how to connect quantum and classical IT, as well as connecting future quantum devices These results are essential for new quantum communication related use cases.

A market of $2 billion by 2027

According to the Insight Partners report titled 'Quantum Cryptography Market To 2027,' the Global QKD market is expected to grow towards $2 billion by 2027 with a compound annual growth rate (CAGR) of 39.2%.

open example

ID Quantique: Quantum-safe security white paper

QKD networks will soon become a reality. QKD is therefore set to become an integral part of a global security framework. In this framework both computational methods and physical methods are used to ensure data security. In particular, it will provide quantum-safe security against the threat of a quantum computer.

open example

TREND #2

Quantum Computing in the Cloud

Public values

Autonomy	Freedom of choice
Justice	Accesibility | Integrity
Humanity	Personal development

Readiness WATCH PLAN ACT

Drivers

#Connectivity #Digital literacy and skills #Research environment

In the last years we have seen the rise of quantum computing. Not only is hardware rapidly developing (we now have computers with up to 433 qubits and many different technologies), but the whole software stack and platforms that give access to quantum computing are rapidly evolving as well. Researchers and students can now access quantum computers through the internet. Access can be granted directly by the quantum computing provider, as is the case in IBM and Quantum Inspire, or via public cloud providers like AWS and Azure. Furthermore, quantum computing providers show increasing interest to engage with end-users to explore use cases that can prove quantum advantage. The quantum computing providers are constantly expanding their portfolio, both on the back-end side (quantum computers available) and on the software/platform side (modules, tutorials, tools for analysis, abstraction layers, etc) to help the onboarding of users and the development of new applications.

Tools and tutorials for quantum computing

Microsoft developed a course for educators to support the development of a quantum-ready workforce. Also, IBM Research developed Qiskit, an open-source software development kit for working with the most widely used programming tool in quantum computing. Qiskit has a very robust set of tutorials, videos and examples available for everyone.

open example open example

Quantum Delta NL action line 3

Quantum technology is still in an early, pre-paradigm phase. In this phase, it is extremely important to focus on talent. In this action line, Quantum Delta NL will focus on educating, training and attracting top talent for strengthening the Dutch innovation capacity that incorporates all the affiliated quantum research institutes.

open example

Quantum.Amsterdam workshops and training

To educate and prepare professionals, Quantum Amsterdam organises workshops and masterclasses on quantum computing. These workshops and masterclasses are aimed at senior management, entrepreneurs and IT staff. For more extensive training on bachelor's and master's level, university courses are available.

open example

Quantum engineering course in the making

All five quantum hubs in the Netherlands are developing University Master programs on quantum information science and technology. This initiative lies by the University of Delft, the University of Leiden, the Eindhoven University of Technology, the University of Amsterdam, and TU Twente. Moreover, the four Applied Science Schools Fontys, HvA, Saxion and HHS, are jointly setting up Talent and Learning Centers and their own Master quantum technology program.

open example

IMPACT

With more quantum computers, information, tutorials, tools and abstraction layers available, there will be a faster adoption of quantum computers. As the adoption of quantum computer grows, so will the need to develop expertise in the field, through establishing curricula. Easy access to quantum computers will enhance the overall understanding of students by providing the possibility for practical experiments. In research, the access to quantum computers will speed up the development of applications and use cases. Access to different technologies will also allow for a better characterization of quantum computers and therefore accelerate knowledge in quantum computing itself. Comparison, testing and benchmarking studies for different algorithms and applications will also increase.

TREND #3

Hybrid quantum/ classical computing

Public values

Autonomy

Justice — Accessibility | Integrity

Humanity

Readiness WATCH PLAN ACT

Drivers

#Digital literacy and skills #Dataism #Connectivity #Digital economy

Hybrid algorithms are currently the only way to exploit NISQ devices and have been proposed for most applications envisioned for quantum computers. However, a hybrid approach is not exclusive to the execution of hybrid algorithms. Every quantum algorithm requires the support of classical resources. Furthermore, in most cases, quantum algorithms will not be executed as isolated instances but as part of larger workflows that combine classical and quantum resources. For complex problems, classical resources will most likely be provided by high performance computing (HPC) centers.

To enable the development of quantum applications, quantum computing providers, and in particular QaaS, are now also including classical resources to their platform to ensure users can execute a wider range of experiments. HPC centers are becoming the earliest adaptors of quantum computers and/or simulators and working together with quantum providers to integrate quantum and classical resources.

NVIDIA Announces Hybrid Quantum-Classical Computing Platform

The hybrid quantum-classical capabilities provide an efficient way to program quantum and classical resources in a consolidated environment. This enables HPC developers to accelerate their applications, in chemistry, the development of new medicines, materials science and other disciplines. The integration with quantum computing allows for new discoveries as quantum advantages emerge.

open example

European investment on <HPC | QS > infrastructure

<HPC | QS > seeks to integrate and couple two quantum simulators, each capable of controlling more than 100 qubits, with two existing European Tier-0 supercomputers, and to deploy an open European federated hybrid HPC-QS infrastructure that will provide non-commercial cloud access to public and private European users.

open example

Accelerate hybrid quantum-classical algorithms on Amazon Braket

Research into hybrid quantum/classical algorithms is an important paradigm in the NISQ era of quantum computing. The performance-optimised software-based simulators from PennyLane, powered by NVIDIA, allow researchers to push the boundaries of research on hybrid quantum/classical algorithms.

open example open example

IMPACT

Several research fields (for example chemistry, machine learning, financial modelling, logistic optimisation, climate simulations, etc.) can migrate parts of their current HPC applications to quantum computers. This migration could speed up the experiments and hence the research in these areas exponentially.

Hosting of quantum computers

The European High Performance Computing Joint Undertaking (EuroHPC JU) has selected six sites across the European Union (EU) to host and operate the first EuroHPC quantum computers: Czech Republic, Germany, Spain, France, Italy, and Poland.

open example

High performance computing centers early adopters of quantum computing

Several HPC centers have already acquired and integrated quantum simulators and quantum computers into their resources.

open example open example open example

Forbes: The quantum revolution is here, its name is hybrid

Classical and quantum computers will work together to tackle difficult problems. Hybrid computing will give non-quantum users access to quantum capability, primarily through the cloud. The classical computer will never go away, and without them quantum computers are never going to realise their full potential either.

open example

TREND #4

Error correction techniques

Public values

Autonomy

Justice

Integrity

Humanity

Readiness WATCH PLAN ACT

Drivers

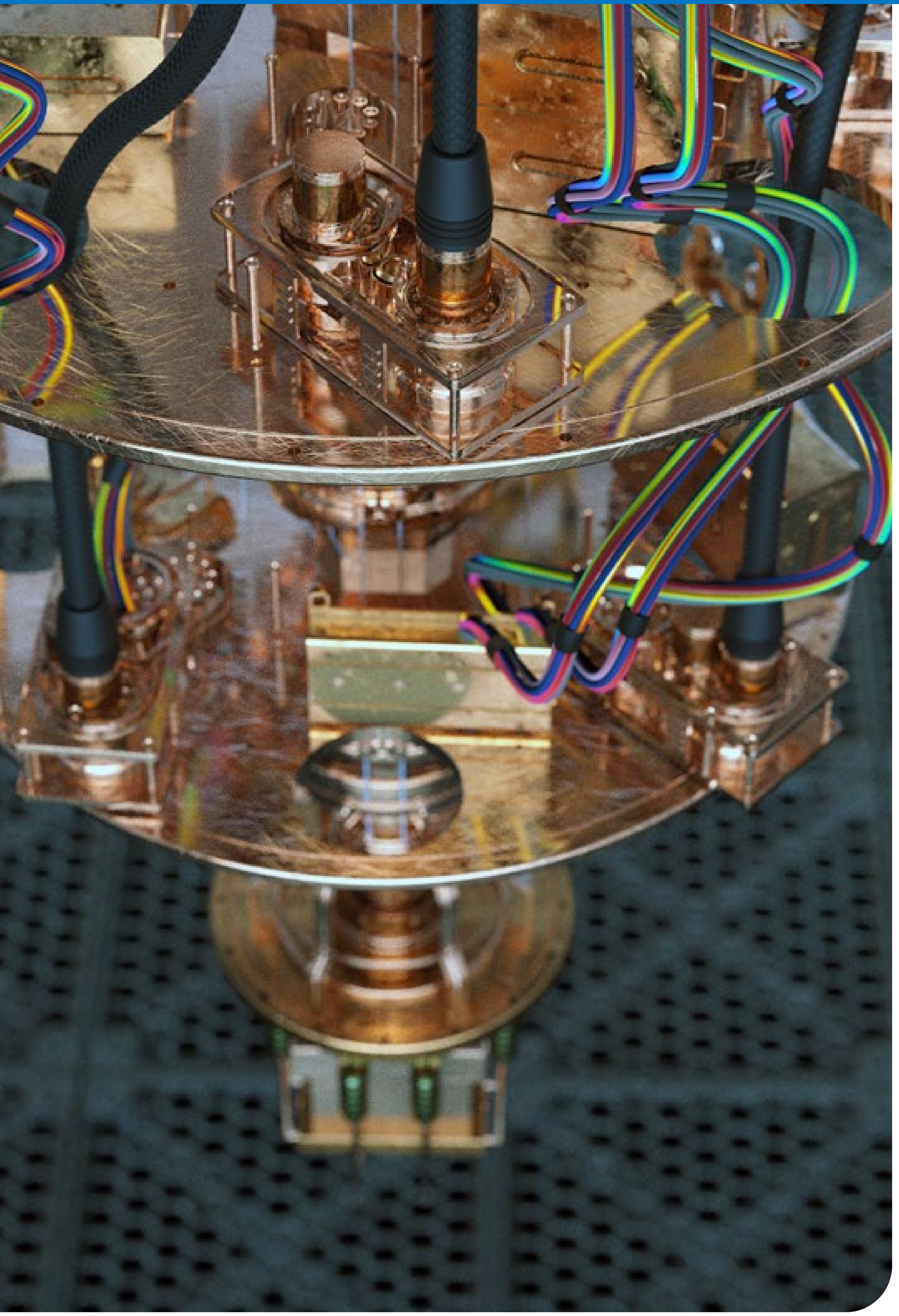
#Connectivity #Data governance

Qubits are delicate, unstable and prone to errors that can quickly lead to faulty computations. Decoding these errors on even a 'small' quantum computer requires real time identification and correction of billions of errors per microsecond. In order to be able to use quantum computers, we need error correction. In quantum error correction, quantum information is distributed among many qubits, so that the dominant noise processes affect quantum information in a reversible manner. This means that an error reversal procedure is employed to detect and correct the errors. There are currently many efforts in the development of advanced error correction techniques. Quantum error correction is a critical technique for transitioning from noisy intermediate-scale quantum devices to universal quantum computers. The surface code, which has a high threshold error rate, is the leading quantum error correction code for two-dimensional grid architecture." [Youwei Zhao et al. Phys. Rev. Lett. 129, 030501 (2022)]

The big impact of quantum error correction

To do complex calculations, we must drastically scale up the number of high-quality qubits. Without error correction, a quantum computer's answers could be nonsense. To make quantum computers useful, we need to reduce the impact of errors in our computations. There are different ways and levels of handling errors. For example, IBM currently looks at quantum error management through the lens of three methods: error suppression, error mitigation, and error correction However, the ultimate goal: fault-tolerant quantum computations requires the development of quantum error correction techniques.

open example open example



How IBM Quantum is advancing quantum error correction with hardware experiments

This article demonstrates the importance of performing real experiments in implementing our error correcting codes onto quantum hardware. Not only can they help to advance theory, but they can also tell us what kinds of coding and decoding schemes work best for the hardware that we're constructing and show us what kinds of errors to expect in the real world. These experiments even provide new ideas that theory may not have anticipated.

open example

The path to useful quantum computers with error correction

During the IEEE Quantum Week in September 2022, a variety of workshops and keynotes highlighted the emerging engineering challenges for getting quantum computing 'to scale'. We also learned more about the burgeoning ecosystem focusing on error-corrected machines.

open example

IMPACT

Most quantum algorithms require billions of gates, and hence require extensive error correction. Once mature fault-tolerant computers exist, end-users can operate them much more similar to a conventional computer, as they simply execute the logical instructions without worrying about mistakes.

TREND #5

Quantum curiosity

Public values

Autonomy

Justice Equality

Humanity

Readiness WATCH PLAN ACT

Drivers

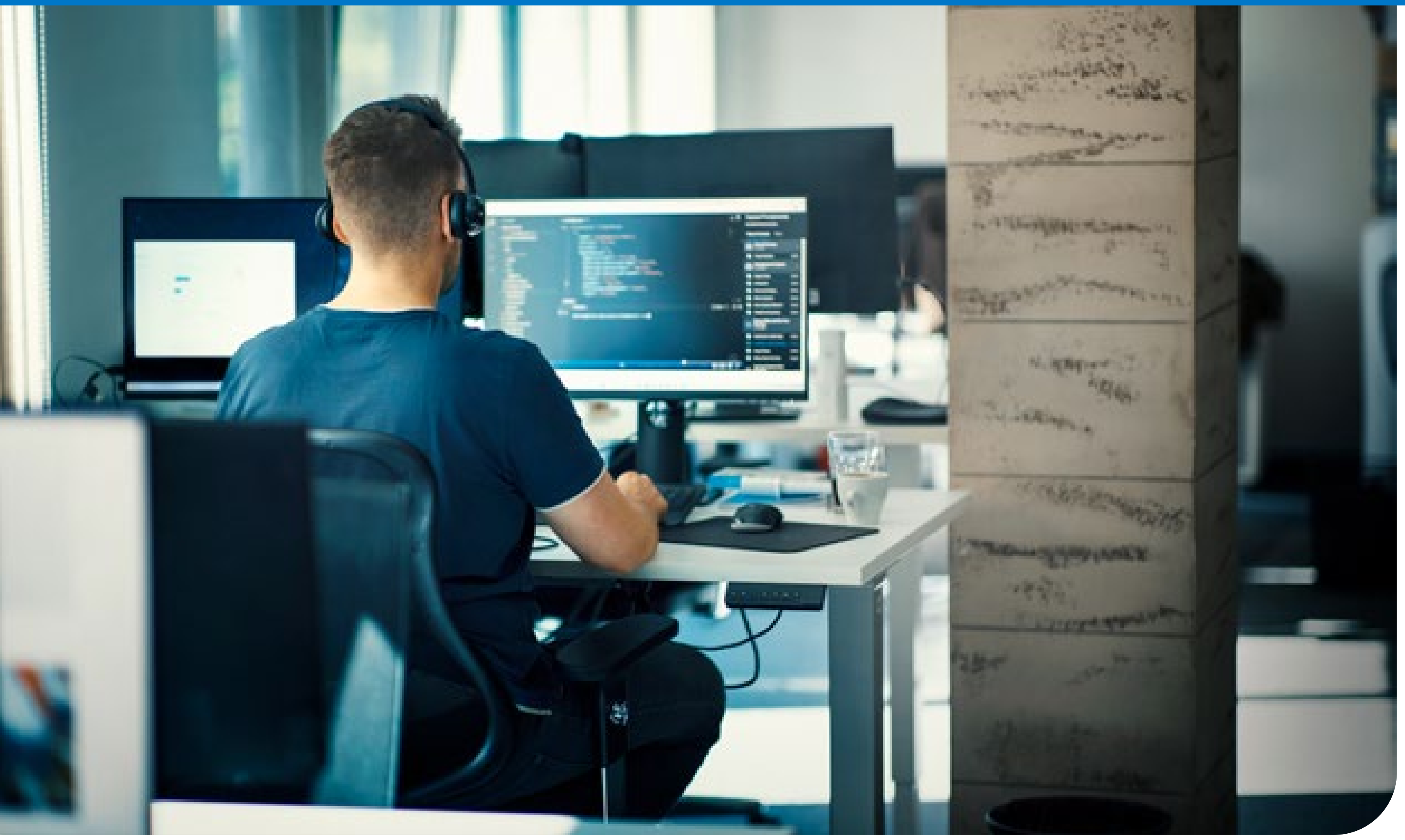
#Dataism #Cyber security #Research environment

Quantum technologies are becoming sufficiently mature to be commercialised and a growing number of people are curious to explore possibilities and opportunities. Research institutions and private enterprises are increasingly teaming up to patent developments. Venture capitalist and governments are investing large amounts of money. Big companies are also investing in start-ups to increase their capabilities. Companies are investing and exploring quantum out of fear of missing out.

QDNL calls SME's for applications

SMEs can submit projects as individual companies or in a public-private partnership consortium from EUR 500,000 to EUR 2 million per project. Quantum SME aims to fund annually recurring calls of EUR 5 million per year for the further development of quantum technology.

open example



Quantum Delta NL launches two million euro micro fund for quantum startups

Quantum Delta NL launched a EUR 2 million micro fund called 'LightSpeed Fund 1'. The fund will support early stage quantum start-ups. If a start-up fails, it does not have to repay a EUR 50,000 pre-seed ticket.

open example

IMPACT

More jobs and opportunities for students with quantum technology knowledge. More collaborations with private sector and funding opportunities.

Capgemini launches a dedicated quantum lab

Capgemini has signed an agreement with IBM to become an IBM Quantum Hub. This hub will provide Capgemini's clients access to IBM's quantum computing systems, including IBM's recently announced 127 qubit processor 'Eagle'. The hub will also give access to IBM's quantum expertise and to Qiskit, IBM's open-source quantum information software development kit. By working with IBM, Capgemini joins more than 170 IBM Quantum Network members, all working to advance quantum computing and explore practical applications.

open example

Quantum Applications Lab

QAL will fullfill the much-needed connection between scientific developments of quantum hardware and software and demand-driven solutions for e.g. optimisation, simulation, and machine learning. Embedded in the Quantum Delta NL (QDNL) ecosystem, QAL will accelerate the construction of a social and economic innovation infrastructure for quantum computing and the knowledge, capabilities, and competencies required for this. QAL will do this by identifying promising domains for quantum computing applications and executing projects together with scientific, industrial, and/or private sector partners.

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