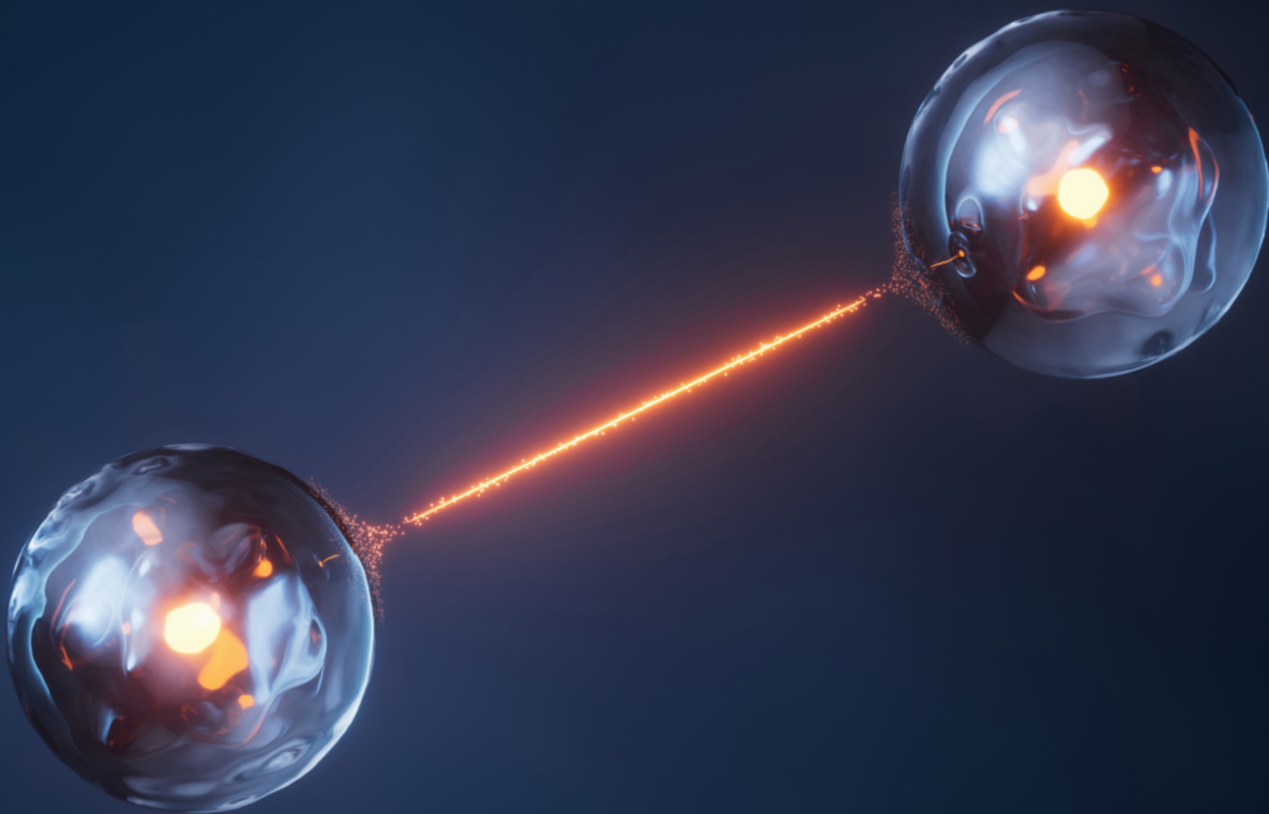
Part of the conference series
Transforming our future

Quantum information

19 – 20 February 2025

Conference report



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This document is not a verbatim record, but a summary of the discussions that took place during the event and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society.

Contents

Introduction

On 19 – 20 February 2025, the Royal Society hosted a hybrid conference on Quantum information.

The United Nations has proclaimed 2025 as the International Year of Quantum Science and Technology. This conference was the inaugural event in the UK's year-long celebration of quantum science and its applications.

This event was delivered as part of the Royal Society's *Transforming our future* conference series. Meetings in this series bring together experts from industry, academia, funding bodies, the wider scientific community and government to explore and address key scientific and technical challenges of the coming decade. These conferences are organised with the support of the Royal Society's Science, Industry and Translation Committee.

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A summary of key discussion points along with abstracts of the talks and overviews of the panel sessions are presented in this report.

This document is not a verbatim record, but a summary of the discussions that took place during the event and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society.

Presentations from the conference are available to watch online. The talks are only available on the linked playlists:
Day one: **youtu.be/ytqFQxPTTAY**
Day two: **youtu.be/TMi8pDQ0wK0**

"This excellent and long-planned event provided an ideal start to the UK's celebrations of IYQ 2025 and it was a privilege to be involved. The presentations and panel discussions were uniformly excellent and provided much food for thought amongst the very wide range of in-person and on-line attendees. The recordings of the talks provide an important resource for future reference which I expect to be widely utilised."

Professor Martin Dawson FRS, University of Strathclyde, conference organiser.

Executive summary

The Quantum information conference held on 19 – 20 February 2025 brought together speakers from industry, academia and government to discuss both the history and future of quantum computing and networks.

Image: Professor Leigh Lapworth, Rolls-Royce plc, conference organiser.

Over two days, industry leaders, top scientists and key public sector stakeholders convened to highlight advances and prospects in quantum information and consider the scientific and technical challenges facing the field. These were set into historical and current context by a keynote presentation from Sir Peter Knight FRS and framed for the future by a keynote presentation from Professor Jian-Wei Pan FRS. Discussions focused on quantum information processing and related technologies, examining what support is needed to scale existing technologies and which predictions for the future are both ambitious and realistic.

> "I was honoured to be part of this fantastic start to the UK Year of Quantum, it gave a perfect balance of the nearer and longer term opportunities for quantum information."
>
> Professor Leigh Lapworth, Rolls-Royce plc, conference organiser.

Key themes that arose during the meeting include:

- **New technologies**
  The emergence of new technological opportunities arising from the phenomenon of entanglement has been a surprise to the community over recent decades. Several speakers made the point that open questions on the foundations of quantum mechanics continue to need exploration and that addressing these may, in turn, lead to further technological developments.

- **Quantum missions**
  The focus of the UK's National Quantum Technology Programme (UK NQTP), and the renewal of its EPSRC-supported Quantum Technology Hubs in Phase 3, is now closely linked to the Quantum Missions agreed with UK Government:
  - **Mission 1:** By 2035, there will be accessible, UK-based quantum computers capable of running 1 trillion operations and supporting applications that provide benefits well in excess of classical supercomputers across key sectors of the economy.

- **Mission 2:** By 2025 the UK will have deployed the world's most advanced quantum network at scale, pioneering the future of the quantum internet.
- **Mission 3:** By 2030, every NHS Trust will benefit from quantum sensing-enabled solutions, helping those with chronic illnesses live healthier, longer lives through early diagnosis and treatment.
- **Mission 4:** By 2030, quantum navigation systems, including clocks, will be deployed on aircraft, providing next-generation accuracy for resilience that is independent of satellite signals.
- **Mission 5:** By 2030, mobile, networked quantum sensors will have unlocked new situational awareness capabilities, exploited across critical infrastructure in the transport, telecoms, energy and defence sectors.

- **Hybrid quantum-classical computing**
  Several speakers discussed the importance of infrastructure and systems involving co-located/networked quantum and classical computers at scale. Of particular interest is the "European Federated Hybrid HPC/QC Infrastructure", which involves nine datacentres in France, Finland, Germany, Italy, Poland and Spain.
- **The role of AI**
  This was not seen as competitive but rather important in supplementing/complementing quantum computation. There is an expectation that quantum devices will provide new sources of data and information for classical AI.
- **Applications of quantum computing**
  Several speakers drew attention to the community being close to quantum computation applied usefully to real-world problems and the demonstration of quantum advantage in certain limited cases, whilst agreeing that fully scaled fault tolerant systems are still likely to be a decade or more away. For the fault-tolerant systems, the applications have focused on quantum chemistry, and these are expected to be where the first advantages will be seen.

Image: Professor Jonathan Matthews, PsiQuantum, conference organiser.

"In putting together the programme, we wanted to reflect strongly the impact that quantum science and technologies can have on other scientific disciplines."

Professor Jonathan Matthews, PsiQuantum, conference organiser.

- **Choice of hardware**
  There is currently no single preferred hardware platform for quantum computation. Multi-national companies (eg IBM, Google) are largely favouring superconducting qubit systems, where effort seems to be scaling back from number of qubits to quality of qubits and their control. However, many start-up companies, plus much of academia, continue to investigate alternate systems (eg those based on trapped ions, neutral atoms, silicon, diamond, SiC, photonics, etc). National centres and facilities are 'spread betting' and building up broad experience by implementing test beds and demonstrator systems based on a range of these platforms. Examples include the facilities at the National Quantum Computing Centre and Forschungszentrum Jülich.

Image: Louis Barson, Institute of Physics, described plans in the UK for celebrating the UN International Year of Quantum Science and Technology.

- **Scaling quantum technology**
  Independently of the qubit modality, building industrial scale computers relies on being able to scale the hardware both up and out. This will require modular design. There is a need to increase both number and quality of qubits to progress towards fault-tolerant quantum computing. However, there are applications where current devices can feasibly provide a meaningful quantum advantage, possibly within a year or two. Algorithm developments can offer orders of magnitude improvement in performance.

- **Consolidation**
  This is to be expected in the commercial approaches to quantum computation amongst the above-stated hardware problems. Acquisitions and mergers are likely to define the future form of the industry.

- **'Quantum winter' unlikely**
  There was a general consensus amongst contributors that a 'quantum winter', during which funds and resources become scarce, is unlikely in the near-term. Rather, they anticipate a landscape where quantum capability increasingly becomes part of established business models and scaled industry. Government funded R&D in this area is expected to continue given strong national and international commitments driven by societal and economic issues such as defence, communications, IT infrastructure and healthcare.

- **The role of photonics**
  Photonics has a very important and increasingly large role to play across most quantum computing platforms. It is the basis for photonic quantum computation directly, and for other systems it is involved in preparing, addressing, and reading out from qubits. Photonics offers ways to distribute entanglement and is becoming important for implementing distributed and hybrid computational systems. Beyond that, photonics links to the established communications network, both ground and (increasingly) satellite-based and will be essential to establish the quantum internet. It is also the basis of many approaches to quantum sensing and imaging.

- **International perspective**
  Quantum computation and communications research activities in China are amongst those pushing the state-of-the-art. This includes both superconducting and photonics-based quantum computation systems and quantum communications networks ranging from metro systems through to satellite-based networks.

DAY ONE OPENING KEYNOTE

The first 100 years of quantum science: from inspiration to economic and societal value

Sir Peter Knight FRS

To watch the keynote on Youtube, visit: youtube.com/live/ytqFQxPTTAY?start=1073

Sir Peter Knight FRS, National Physical Laboratory and UK National Quantum Technology Programme, highlighted the history of quantum over the last 100 years and described a new era of quantum technologies that will help address society's key challenges.

Image: Sir Peter Knight FRS, National Physical Laboratory and UK National Quantum Technology Programme

"For the International Year of Quantum, in my view there is one thing we really must do: enthuse the next generation about the subject. We must bring people into the fold and listen to them about how they might contribute to the way that quantum will transform society."

Sir Peter Knight FRS,
National Physical Laboratory and UK National Quantum Technology Programme.

These new capabilities include novel sensing, timing, imaging and computing, enabling societal benefit from this transformational technology. Sir Peter described the journey from fundamental science to practical realisation. This new era of quantum technologies will transform economies in our digital age and help to address society's challenges: advancing health care and environmental protection, achieving better land use, supporting financial services and communications and providing extraordinary computing power.

DAY ONE SESSION ONE

Hybrid quantum-classical computing

Session Chaired by Ellen Devereux, Fujitsu UK&I

Watch all session 1 talks at: youtube.com/live/ytqFQxPTTAY?start=3874

TALK ONE

The question of quantum advantage in analogue and digital quantum simulation

Professor Andrew Daley, University of Oxford, compared different approaches to simulating quantum systems whilst analysing their reliability and advantages over simulation on classical computers.

In parallel to rapid developments in quantum computing hardware, highly controlled quantum systems are being applied as analogue quantum simulators to study problems of interest in many-body physics. How do these approaches compare? Under which conditions can the answers we get out be qualitatively reliable? And where can they provide answers to questions we cannot address with simulation on classical computers? Professor Andrew Daley addressed this comparison, and asked where we might expect to obtain a practical quantum advantage for simulation of quantum systems, together with which approaches we might take towards these problems in the early fault-tolerant era of quantum computing.

"When we ask the big question of 'When are we going to be able to do something with quantum computing and quantum simulation that we can't do on a classical computer?', for certain specialised problems in science the answer is 'now'."

Professor Andrew Daley, University of Oxford.

Image: Professor Andrew Daley, University of Oxford.

TALK TWO

Quantum computing: from the basic concepts to the embedding in an HPC environment for application purposes

Professor Kristel Michielsen, Forschungszentrum Jülich GmbH, described the integration of quantum computing into existing high performance computing infrastructures using the example of JUNIQ.

Quantum computing promises unprecedented possibilities for important computing tasks such as quantum simulations in chemistry and materials science or optimisation and machine learning. With this potential, quantum computing is increasingly attracting interest from industry and scientific communities that use high performance computing (HPC) for their applications.

Practical application requires the integration of quantum computers into existing HPC infrastructures in the form of quantum-classical hybrid computing models.

The Jülich UNified Infrastructure for Quantum computing (JUNIQ), a manufacturer-independent quantum computing user facility established at the Jülich Supercomputing Centre (JSC) aims to address these needs.

"Our vision is that in order to move towards practical quantum computing, we will have to combine quantum computing with the best of high-performance computing."

Professor Kristel Michielsen, Forschungszentrum Jülich GmbH.

Professor Michielsen presented benchmarking results for the quantum approximate optimisation algorithm (QAOA) emulated on a supercomputer and for the D-Wave quantum annealers for the tail assignment problem, a planning problem from aircraft industry.

Image: Professor Kristel Michielsen, Forschungszentrum Jülich GmbH.

DAY ONE SESSION TWO

Enabling technology for quantum

Chair: Professor Jennifer Hastie, University of Strathclyde

Watch all session 2 talks at: youtube.com/live/ytqFQxPTTAY?start=8405

TALK ONE

Quantum computers need (huge) classical computers

Dr Steve Brierley, Riverlane, discussed why classical computers are in demand for beneficial quantum computing and the implications that may arise from this.

To build useful quantum computers we are going to need a huge amount of classical computing – from microwave signal generation to real-time decoding for quantum error correction. Dr Steve Brierley reviewed why, what the classical computer is doing and the implications for achieving useful quantum computing at a price point that makes sense.

"The quantum computing journey will be one of science and amazing engineering. The third thing that will enable it is the specialisation of key components within the quantum computing stack."

Dr Steve Brierley, Riverlane.

Image: Dr Steve Brierley, Riverlane.

TALK TWO

Qumodes, flying qubits, and MBQC: How photonics is different from other QC modalities and why that's good

Dr Richard Murray, ORCA Computing, described why photonics is such a different and promising quantum platform.

Photonic quantum information processing sometimes causes head-scratching to the uninitiated. Unlike other quantum particles, photons are always in motion, do not interact directly with each other, and lack a natural 2-level structure. Instead, each photon can be controlled across multiple orthogonal parameters: time, frequency, path, and polarisation. Each dimension of control represents a different way in which they can be encoded… perhaps even all at once!

In this talk, Dr Richard Murray embraced the unique nature of photons and explored how leveraging every distinct characteristic can help build efficient systems to address the challenges facing generative AI applications today.

> "When you look at quantum computing, you see a dichotomy: you see sometimes people present systems with perfect qubits with long coherence times, or you see people reporting systems with lots of control and operations. It is hard to see platforms that are truly in the middle, ones that have true isolation with control."
>
> Dr Richard Murray, ORCA Computing.

Image: Dr Richard Murray, ORCA Computing.

TALK THREE

Transformative value of quantum and AI: bringing meaningful insights for critical applications today

Dr Elvira Shishenina, Quantinuum, highlighted the advancement in computational capabilities driven by its cutting-edge hardware, which integrates quantum technology with AI and HPC to tackle real world challenges.

The ability to solve classically intractable problems defines the transformative value of quantum computing, offering new tools to redefine industries and address complex humanity challenges. Quantinuum's hardware is leading the way in achieving early fault-tolerance, marking a significant step forward in computational capabilities. By integrating quantum technology with AI and high-performance computing, Quantinuum are building systems designed to address real-world issues with efficiency, precision and scale. This approach empowers critical applications from hydrogen fuel cells and carbon capture to precision medicine, food security, and cybersecurity, providing meaningful insights at a commercial level today.

"By bridging the gap between quantum technology, generative AI and high-performance computing, and enhancing it with the subject-matter expertise from our partners, we believe we will be able to reshape the future of innovation, today."

Dr Elvira Shishenina, Quantinuum.

Image: Dr Elvira Shishenina, Quantinuum.

DAY ONE SESSION THREE

How can quantum technologies scale?

Chair: Professor Leigh Lapworth, Rolls-Royce plc

Watch all session 3 talks at: youtube.com/live/ytqFQxPTTAY?start=15698

TALK ONE

Distributed quantum computation via the Entanglement Fabric

Dr Carmen Palacios-Berraquero, Nu Quantum, demonstrated the advantages and impact of networking small, robust QPUs to create a large coherent computer via an error-correctable Entanglement Fabric.

2024 was an important year for the Quantum Computing industry. Two major conditions for quantum computation were demonstrated: the ability to create high-fidelity physical qubits, and the ability to perform quantum error-correction on those qubits to achieve even-higher (useful) fidelities. Now that we have achieved high-quality and stable qubits, the only orders-of-magnitude challenge left is scaling: whereas Quantum Processing Units (QPU) will be able to host 1 – 10k good physical qubits in a single chip or module, for utility, industry consensus is that circa 100k-1M physical qubits will be required.

This talk described how networking of small and robust QPUs to create a large coherent computer via an error-correctable Entanglement Fabric has recently been demonstrated by Nu Quantum to be viable, feasible, and efficient path to scale. This approach - usually referred to as 'Scale-out' in classical computation - can offer a predictable engineering roadmap to scale for quantum computation, and eventually for sensing and communications.

Image: Dr Carmen Palacios-Berraquero, Nu Quantum.

"In 2024, two technology barriers have been solved: we now have stable and error-corrected qubits. However, we have very few of them. The challenge of scaling remains, and this is a many orders-of-magnitude challenge."

Dr Carmen Palacios-Berraquero, Nu Quantum.

TALK TWO

Foundry semiconductor manufacturing as an optimal path to making utility scale quantum

Dr Maksym Sich, Aegiq, discussed the challenges in quantum computing and how Aegiq tackles these with an integrated photonic approach, utilising semiconductor manufacturing driven by telecommunications and AI industries.

Is it possible to solve efficiency, scalability and compatibility with existing infrastructure bottlenecks together in order to unlock useful quantum computing? Aegiq addresses this critical challenge by leveraging advances in high-volume semiconductor manufacturing driven by telecommunications and now AI industries. This talk provided an overview of Aegiq's integrated photonic approach operating fully at the standard telecom wavelength for embedded connectivity and the path towards commercial advantage it offers.

> "Aegiq use photonics to build the foundational products for creating, securing and processing quantum information."
>
> Dr Maksym Sich, Aegiq.

Image: Dr Maksym Sich, Aegiq.

TALK THREE

The role of metrology in making quantum technologies scale

Professor Alexander Tzalenchuk, National Physical Laboratory, Royal Holloway, University of London, discussed the need for a new generation of *in-operando* metrology in emerging technology, such as quantum computing, and shared examples of relevant work in this area.

Different quantum technologies require different scale to be useful. In any case, scale-up is not just a matter of making more qubits, but also a matter of making each of them – and all of them together – well. Metrology has an important role to play in evaluating the performance of quantum technologies all the way from relevant materials to systems. Relevant tests and procedures for the characterisation of optical components for use in quantum key distribution systems have already been standardised. Other less mature technologies such as quantum computing also require characterisation, benchmarking, and evaluation – both platform-specific and agnostic – to inform development and prioritise investment in supply chains and final products. Among other advancements, this calls for a new generation of *in-operando* metrology, and Professor Alexander Tzalenchuk gave examples of relevant work in this direction.

> "Quantum technologies are already scaling up and must continue to do so much further to become useful. Metrology can help along the way."
>
> Professor Alexander Tzalenchuk, National Physical Laboratory, Royal Holloway, University of London.

Image: Professor Alexander Tzalenchuk, National Physical Laboratory, Royal Holloway, University of London.

DAY ONE PANEL DISCUSSION

Quantum innovation – what support is needed?

Chair: Professor Roberto Desimone, Plantagenet Systems
Watch the panel discussion at: youtube.com/live/ytqFQxPTTAY?start=21086

Professor Roberto Desimone, Plantagenet Systems, chaired a panel discussion on the many different aspects of support needed to accelerate innovation in quantum science.

Long-term investment is a key part of boosting ongoing innovation in quantum. However, many other types of assistance are needed from a range of stakeholders to create and maintain an environment where quantum innovation can thrive.

A panel of four speakers explored this theme in more detail. Dr Steve Brierley, Riverlane; Professor Eleni Diamante, CNRS and Sorbonne University; Ilyas Khan, Quantinuum; and Jonathan Legh-Smith, UKQuantum spoke about a wide range of topics, including:

- **Funding and international collaboration**
  - Is the right kind of funding available, both in the UK and elsewhere, to support this innovation? From which sources?
  - How strong are international collaborations?
- **Infrastructure and standards**
  - What infrastructure is needed to support innovation programmes?
  - How important are standards for quantum innovations, and what standards are being developed to encourage interoperability?
  - How much is being done to understand how complex hybrid quantum-classical systems can be engineered?
- **Regulation and ethics**
  - What efforts are in place to address ethical concerns about innovation with quantum-enabled solutions? Is enough being done?

Questions from the audience covered additional topics on the need for improved skills and training in quantum; whether AI presented an opportunity or threat to the development of quantum computing; and what other applications, beyond modelling quantum mechanical simulations, might be possible with existing and near-future systems.

> "Not only were the speakers insightful and informative about future developments in quantum computing/information, but the audience raised key questions that helped us understand the challenges."
>
> Professor Roberto Desimone, Plantagenet Systems, conference organiser.

Image: (left to right) Ilyas Khan, Quantinuum; Jonathan Legh-Smith, UKQuantum; Professor Eleni Diamante, CNRS and Sorbonne University; Dr Steve Brierley, Riverlane; and Professor Roberto Desimone, Plantagenet Systems, conference organiser and Chair of the panel.

DAY TWO OPENING KEYNOTE

Quantum entanglement and beyond

Professor Jian-Wei Pan ForMemRS, University of Science and Technology of China
To watch the keynote on Youtube, visit https://youtu.be/TMi8pDQ0wK0?start=724

Professor Jian-Wei Pan ForMemRS, University of Science and Technology of China, described how to experimentally test quantum entanglement, methods to translate quantum information technology from theoretical concepts to reality and highlighted the future prospects of the global quantum communication network.

Quantum entanglement reflects the essential differences between classical and quantum physics. The nonlocality and intrinsic randomness of quantum entanglement not only deepen our understanding of the laws of quantum world, but also give rise to emerging quantum information technologies, including quantum communication and quantum computation, which can ensure secure information exchange and greatly enhance the computing power, respectively. Professor Jian-Wei Pan introduced how to experimentally test quantum entanglement and how to turn quantum information technology from purely theoretical concepts into reality. Specifically, how to overcome the security loopholes caused by imperfection of realistic devices, how to extend the distance of quantum communication, and how to use the coherent manipulation of multiple qubits to achieve a quantum computer that can surpass classical supercomputers. He also introduced the future prospects of the global quantum communication network and its new applications in the field of quantum metrology, as well as the development roadmap of quantum computing.

"In the next 10 – 15 years, we hope to achieve coherent manipulation of millions of qubits. This will lay the foundation for universal quantum computation with the help of quantum error correction."

Professor Jian-Wei Pan ForMemRS, University of Science and Technology of China.

The future of quantum

Chair: Professor Martin Dawson FRS, University of Strathclyde
Watch all session 4 talks at: https://youtu.be/TMi8pDQ0wK0?start=3245

TALK ONE

Photonic quantum information processing and sensing: future challenges

Professor John G Rarity FRS, University of Bristol, discussed the scalability of integrated quantum photonics as well as the applications of other quantum photonic technologies in imaging, sensing and rangefinding.

Over 30 years ago we moved from trying to prove the counter-intuitive correlations predicted by quantum mechanics are correct when Artur Ekert showed we could use them to generate secure truly random bit strings (keys) at remote locations. Later the concept of qubits and gates led Schor to discover exponential speed up is possible. Since then astounding experimental progress has led to intermediate scale quantum computing demonstrators showing quantum supremacy in hero experiments.

The ability to scale without incurring debilitating errors and loss beyond 100 physical qubits is now the remaining challenge. Here Professor John G. Rarity focused on integrated quantum photonics with high gate fidelity but low efficiency. He discussed possible directions that may make this approach scalable in the future. Other quantum photonic technologies exploit quantum entanglement in imaging, sensing and rangefinding. He showed that in practice the large sensitivity gains come from using photon counting detectors in rangefinding and gas sensing applications.

Image: Professor John G. Rarity FRS, University of Bristol.

"This is what I see as a potential future for photonic quantum computing: we are going to have to go towards something more deterministic, and we're going to have to integrate that with a low-loss platform to make a more efficient photonic quantum computer."

Professor John G. Rarity FRS, University of Bristol.

TALK TWO

Quantum learning machines

Professor Gerard Milburn FRS, University of Sussex, highlighted the thermodynamics of learning machines and compared the thermodynamic and quantum computational advantage.

Why does AI consume so much energy? What are the physical constraints on machines that learn? Professor Gerard Milburn discussed the thermodynamics of learning machines with a particular emphasis on experimental implementations using superconducting circuits and nano electronics. Quite apart from a thermodynamic advantage, does quantum offer any computational advantage? Current indications suggest that while quantum offers energy efficiency it may not give a computational advantage. He offered a more optimistic assessment based on recent work in quantum chaos.

"The real question is, 'What is the minimum power consumption of a learning machine?'."

Professor Gerard Milburn FRS, University of Sussex.

Image: Professor Gerard Milburn FRS, University of Sussex.

Quantum in the sciences

Chair: Professor Jonathan Matthews, PsiQuantum
Watch session 5 talks at: youtu.be/TMi8pDQ0wK0?start=7805

TALK ONE

Quantum sensing in the life sciences

Dr Helena Knowles, University of Cambridge, highlighted the applications of quantum sensors and presented an overview of the advances in a quantum enabled future of early disease diagnosis, driven by the Q-BIOMED Hub.

Quantum sensors based on optically addressable spins in solids and on atomic vapour cells can offer unprecedented sensitivity and spatial resolution. In recent years, their application to life sciences and the bio-medical field has led to new opportunities and promises to offer dramatically enhanced early diagnosis technologies. In the UK, this effort is accelerating through the newly established Quantum Technologies Hubs. The Q-BIOMED Hub in particular is focused on delivering the quantum-enabled future of early disease diagnosis and treatment. Dr Helena Knowles presented an overview of the Hub, along with some recent highlights of nanoscale quantum sensing from her group in Cambridge. She also showed how very similar devices can be used both for quantum sensing and for quantum simulation applications.

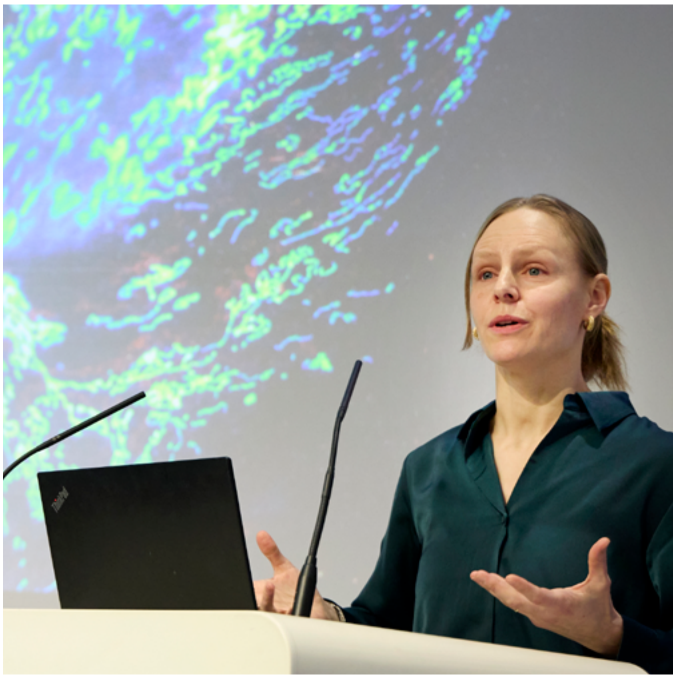

Image: Dr Helena Knowles, University of Cambridge.

"Earlier diagnoses enabled by quantum technologies, such as through ultra-sensitive tests to detect lower biomarker levels and improved access through lower costs and portable instruments, would offer a paradigm shift in healthcare."

Dr Helena Knowles, University of Cambridge.

TALK TWO

What quantum technology can still teach us about foundations

Professor Alessandro Fedrizzi, Heriot-Watt University, discussed which classical concepts conflict with quantum mechanics and how rapidly improving quantum technology will help obtain more conclusive answers.

The Year of Quantum celebrates the 100-year anniversary of the initial development of quantum mechanics — a paradigm shift which raised serious questions about our classical understanding of reality. Some of these questions were formalised by John Bell in his famous theorem, which was conclusively validated in favour of 'quantum reality' only a decade ago. In this talk, Professor Alessandro Fedrizzi argued that this was not an end but a new beginning for further discovery on the big foundational questions which have been driving quantum technology research and vice versa. He reviewed several research strands that have plugged away at the question of which classical concepts are ultimately at odds with quantum mechanics and outlined how rapidly improving quantum technology will help us obtain more conclusive answers.

"We can learn a lot about the foundational questions in quantum science from further technological developments, and at the same time the foundational questions keep driving technological progress."

Professor Alessandro Fedrizzi, Heriot-Watt University.

Image: Professor Alessandro Fedrizzi, Heriot-Watt University.

TALK THREE

Seeing in 3D through an endoscope-like instrument the thickness of a single human hair

Professor Miles Padgett FRS, University of Glasgow, showcased that it is possible to use holographic techniques to shape laser beams and, as a result, create minimally invasive endoscopic systems with improved imaging in complex environments.

Traditional endoscopes use bundles of optical fibres to relay an image, pixel by pixel along their length. Typically these bundles total a few millimetres in diameter, setting a limit to which they perturb the system into which they are inserted. In recent years several groups, including ourselves, have shown it possible to use holographic techniques to shape laser beams in such a way as to create endoscopic systems using only a single optical fibre the width of a human hair, thereby making the endoscope minimally invasive. Moving to the quantum realm we measure the arrival time of individual photons which, knowing the speed of light, allows us to create 3D images giving improved imaging, especially in complicated environments. Professor Miles Padgett FRS and his team are currently working in several application areas with an interest in looking for more, especially those within a clinical setting.

"A traditional endoscope is made from a bundle of optical fibres, one fibre for every pixel in the image, hence are large in diameter. By contrast, we are able to get an image from a single fibre, making the instrument much less invasive."

Professor Miles Padgett FRS, University of Glasgow.

Image: Professor Miles Padgett FRS, University of Glasgow.

Which quantum predictions are ambitious whilst also realistic?

Chair: Professor Leigh Lapworth, Rolls-Royce plc
Watch all session 6 talks at: youtu.be/TMi8pDQ0wK0?start=14808

TALK ONE

Are we nearly there yet?

Professor Ashley Montanaro, Phasecraft, discussed the lack of clear demonstration of quantum advantage over classical computers and the prospect of achieving this.

Following exciting recent progress in the development of quantum hardware, multiple quantum technology platforms have executed computations which are apparently beyond the capability of the world's best classical computers to reproduce. However, there has as yet been no unambiguous demonstration of "quantum advantage": quantum computing solving a problem of outside interest better than classical computers can. In this talk, Professor Ashley Montanaro discussed the prospects for achieving quantum advantage in the near future, and the essential role played by the development of efficient quantum algorithms.

"We are on the cusp of quantum advantage and I believe that meaningful problems will be solved before we have fully fault-tolerant quantum computers."

Professor Ashley Montanaro, Phasecraft.

Image: Professor Ashley Montanaro, Phasecraft.

TALK TWO

Beyond NISQ – what will we find on the pathway to a tera-QuOp?

Dr Michael N Cuthbert, National Quantum Computing Centre, highlighted the NQCC's key programs and their role in supporting UK Quantum Missions, with the goal of achieving a UK-based quantum computer by 2035.

Dr Michael Cuthbert described the role of National Quantum Computing Centre and its flagship QC testbed programme, as well as its test and evaluation programme, user engagement programme and role in supporting the UK Quantum Missions. He identified a number of key milestones and ambition for Mission 1: by 2035, there will be accessible, UK-based quantum computers capable of running 1 trillion operations[1] and supporting applications that provide benefits well in excess of classical supercomputers across key sectors of the economy.

> "It is right to take a portfolio approach on qubit modality, as these scale towards the MquOp. Single purpose machines will have their day; general purpose machines will take longer than we want."
>
> Dr Michael N Cuthbert, National Quantum Computing Centre.

Image: Dr Michael N Cuthbert, National Quantum Computing Centre.

1. 1 trillion operations refers to the number of operations a quantum computer can perform before a single logical error occurs. This compares to a few hundred error free quantum operations on today's fastest machines. It is estimated such a task could take between a few minutes and a few days depending on the design of the computer. Timing expectations will be further defined as the mission programme progresses.

TALK THREE

The role of photonics in real-world deployment of quantum technologies

Professor Jennifer E. Hastie reviewed recent innovations in key photonics technologies that are driving breakthroughs in applications in many industries and highlighted scalability, stability and integration challenges addressed by photonics.

Often the most ambitious challenges in quantum science are in transitioning technologies from the laboratory to real-world deployment, to meet predictions of societal benefit. Achieving this will rely critically on advances in photonics. Professor Hastie briefly reviewed recent innovations in key underpinning photonics technologies such as narrow-linewidth lasers, frequency combs and integrated photonics for high-precision quantum sensors, optical clocks, and interferometry. These innovations are already driving breakthroughs in navigation, Earth observation, medical diagnostics, and fundamental physics. She discussed how photonics is addressing scalability, stability, and integration challenges, paving the way for deployable quantum technologies that will revolutionise scientific and industrial applications.

"Many of the most promising quantum systems still require significant advances in photonics for performance, stability, scalability, and integration, making it a key enabling field."

Professor Jennifer E Hastie, University of Strathclyde.

Image: Professor Jennifer E. Hastie, University of Strathclyde.

DAY ONE PANEL DISCUSSION

What is the future of quantum?

Chair: Professor Jim Al-Khalili CBE FRS, University of Surrey

Watch the panel discussion at: youtu.be/TMi8pDQ0wK0?start=20510

Professor Jim Al-Khalili CBE FRS, University of Surrey, led a lively panel discussion that aimed to distil the key messages from the conference and contemplate how quantum technologies may shape the next decade.

The chair was joined by four panellists: Dr Philip Ball, freelance writer; Professor Winfried Hensinger, University of Sussex; Roger McKinlay, UKRI; and Professor Ruth Oulton, University of Bristol.

The panellists reflected on the themes covered during the meeting and shared their views on what the future might hold for the field of quantum science. Some of the topics covered included:

- **Takeaways from the meeting**
  - In quantum mechanics, there has always been a crucial interaction between the fundamental science and its applications.
  - The UK Quantum Technologies Programme, kick-started a decade ago, has enabled the UK to become a world leader in quantum computing, both in terms of hardware and algorithms.
  - There have not been many revolutions in terms of how we do computing. Advances in quantum computing may inspire a wider array of unconventional types of computing.
  - International collaborations are an important part of ensuring everyone can benefit from quantum advances. Researcher mobility enables these collaborations.
- **Hype vs reality**
  - Companies often make bold statements about what they plan to achieve to receive investment, even if those targets are unrealistic.
  - Many people are intimidated by quantum science. Explaining potential applications is a way to engage broader society in the discussion and encourage governments to invest in fundamental science.
- **Industry interest in quantum science**
  - Timelines for delivery of quantum computing are highly uncertain.
  - Large businesses know it may years to roll out a solution to, for example, quantum attacks on data security. Many are investing in quantum technologies now as part of a long-term strategy, even though the applications (and risks) of advances in quantum computing may be decades away.

Questions from the audience covered additional topics including the availability of tools for public engagement, particularly in schools; whether a 'quantum winter' is likely; and what the original quantum pioneers might be most surprised about if they could see the recent advances in the field.

"We are talking about AI, perhaps not always sensibly, but we are not yet talking in the same way about quantum technologies and what they will mean for society."

Professor Jim Al-Khalili CBE FRS,
University of Surrey, Chair of the panel.

Image: (left to right) Roger McKinlay, UKRI; Professor Ruth Oulton, University of Bristol; Professor Winfried Hensinger, University of Sussex; Dr Philip Ball, freelance writer; and Professor Jim Al-Khalili CBE FRS, University of Surrey, Chair of the panel.

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Organisers
Professor Martin Dawson FRS, University of Strathclyde
Professor Roberto Desimone, Plantagenet Systems
Professor Elham Kashefi, University of Edinburgh, National Quantum Computing Centre and Sorbonne University
Professor Leigh Lapworth, Rolls-Royce plc
Professor Jonathan Matthews, PsiQuantum

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