Frontiers in Quantum Computing

Inaugural Conference
October 18–20, 2021
Kingston Campus

uri.edu/quantum

THE UNIVERSITY OF RHODE ISLAND
COLLEGE OF ARTS AND SCIENCES
DEPARTMENT OF PHYSICS

	FRONTIERS IN QUANTUM COMPUTING **Agenda**		
	Oct. 18 **MONDAY**	**Oct. 19** **TUESDAY**	**Oct. 20** **WEDNESDAY**
7:30 AM	Coffee/Tea & Refreshments	Coffee/Tea & Refreshments	Coffee/Tea & Refreshments
8:00 AM	Welcome/Introduction	**Session IV: Quantum Simulation and Metrology** Chair: Leonard Kahn Speaker: Travis Humble (ORNL)	**Session VII: Quantum Algorithms** Chair: Christopher Savoie Speaker: Alán Aspuru-Guzik (Univ. of Toronto)
8:15 AM	**Session I: National Quantum Initiative** Chair: Vanita Srinivasa Speaker: Jake Taylor (NIST/UMD/JQI/QuICS)		
8:30 AM			
8:45 AM		Speaker: Jeremy Levy (Pitt/PQI)	Speaker: Umesh Vazirani (Berkeley)
9:00 AM	Speaker: Rick Muller (Sandia)		
9:15 AM			
9:30 AM	BREAK	BREAK	BREAK
9:45 AM	Speaker: Rhode Island Senator Jack Reed Introduction by URI President Marc Parlange	Speaker: Amir Yacoby (Harvard)	**Session VIII: Quantum Computing in Industry 1** Chairs: Leonard Kahn, Vanita Srinivasa Speaker: Christopher Savoie (Zapata)
10:00 AM			
10:15 AM	**Session II: QIS Education 1** Chair: Jake Taylor Speaker: Chandralekha Singh (Pitt)		
10:30 AM		**Session V: QIS Education 2** Chair: Chandralekha Singh Speaker: Robert Joynt (Wisconsin)	Speaker: Andrew King (D-Wave)
10:45 AM			
11:00 AM	Speaker: Corey Stambaugh (OSTP)	Speaker: Charles Robinson (IBM)	Speaker: Stephanie Simmons (SFU/Photonic)
11:15 AM			
11:30 AM	Speaker: Emily Edwards (IQUIST)	Speaker: Kiera Peltz (Qubit by Qubit)	Speaker: Emily Pritchett (IBM)
11:45 AM			
12:00 - 1:45 PM	Lunch (Sponsored by D-Wave) - Higgins Posters	Lunch (Attendees on their own for lunch) Posters	Lunch (Attendees on their own for lunch) Posters
2:00 PM	**Session III: Quantum Computing Implementations 1** Chair: Jason Petta Speaker: Lieven Vandersypen (TU Delft)	**Session VI: Quantum Computing Implementations 2** Chair: Vanita Srinivasa Speaker: Jason Petta (Princeton)	**Session IX: Quantum Computing Implementations 3** Chair: Vanita Srinivasa Speaker: Mark Eriksson (Wisconsin)
2:15 PM			
2:30 PM			
2:45 PM	Speaker: Chris Monroe (Duke/IonQ)	Speaker: Ferdinand Kuemmeth	Speaker: Will Oliver (MIT/Lincoln Lab)
3:00 PM			
3:15 PM		BREAK	
3:30 PM	BREAK	Speaker: Michelle Simmons (UNSW)	BREAK
3:45 PM	Speaker: Susan Coppersmith (UNSW)		**Session X: Quantum Computing in Industry 2** Chair: Christopher Savoie Speaker: Michael Biercuk (Univ. of Sydney/Q-CTRL)
4:00 PM			
4:15 PM		Speaker: Andrew Dzurak (UNSW)	
4:30 PM	Speaker: Andrea Morello (UNSW)		Speaker: Sergio Boixo (Google)
4:45 PM			
5:00 PM		BREAK	
5:15 PM		**NQI: Current Status and Perspectives** Speaker: Charles Tahan (OSTP/LPS)	Closing
5:30 PM			
5:45 PM			
6:00 PM	**Cruickshank Lecture - Beupre** Umesh Vazirani 6:00 reception (Lobby of Beaupre) 6:30 Lecture	**Roundtable Discussion: Future of Quantum Computing** (Sponsored by D-Wave) Moderator: Christopher Savoie Panelists: Jake Taylor, Michelle Simmons, Catherine McGeoch (D-Wave), Christopher Lirakis (IBM)	
7:00 PM			
8:00 PM			

In person
Online

Exploring the Frontiers of Quantum Information Science

Jake Taylor
National Institute of Standards and Technology (NIST)/University of Maryland/Joint Quantum Institute (JQI)/Joint Center for Quantum Information and Computer Science (QuICS), USA

Quantum information science investigates the limits and capabilities of communication, computation, and measurement. In the past two decades, the emergence of new technologies that work close to these limits has begun to transform both science and technology. I will describe how the developments at the frontier of quantum information science promise to enable new approaches to chemistry and materials science, new methods of measuring questions of interest for an improved understanding of our universe, and open the possibility of vast new industries. At the same time, I will consider the tremendous challenges ahead, in both realizing a society that can create these new technologies and in engineering the complex systems necessary to enable vast new industries.

Quantum Computing: NISQ and Beyond

Rick Muller
Sandia National Laboratories

Quantum Information Science (QIS) promises someday to revolutionize computing and physical simulation, but real impact still appears to be well in the future. I will discuss QIS projects at Sandia National Laboratories that include development and fabrication of near-term, noisy, intermediate-scale quantum (NISQ) devices as well as their use in the DOE/ASCR Quantum Scientific Computing Open User Testbed (QSCOUT). I will also discuss attempts to go beyond the NISQ era made by the Quantum Systems Accelerator, a DOE National Quantum Information Science Research Center that is led by Lawrence Berkeley National Laboratories.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Preparing Students for the Second Quantum Revolution with Core Concepts in Quantum Information Science

Chandralekha Singh
Department of Physics and Astronomy, University of Pittsburgh

In order to inspire future generations to pursue careers in quantum information science and technology (QIST), educators must play a key role in developing curricular materials and engaging students using evidence-based approaches with core QIST concepts at appropriate levels in a variety of classes. As a physics education researcher, I will discuss these types of efforts I have been involved in. We thank the National Science Foundation for support.

Developing the quantum workforce through early engagement

Corey Stambaugh
National Quantum Coordination Office, Office of Science and Technology Policy

Landscape of Quantum Education for K-12 and the public

Emily Edwards
Illinois Quantum Information Science and Technology Center (IQUIST), USA

During the last year and a half, the National Q-12 Education Partnership was launched and numerous programs for quantum workforce development ramped up. In the long-term, emerging programs have the potential to help young learners develop an appreciation for QIS, and even inspire students to pursue a career in this critical area. In addition, introducing QIS concepts early in schools will enable students to build intuition around this topic, and better prepare them for future QIS coursework at the undergraduate level. Extending QIS learning opportunities to younger age groups is also critical towards growing a more inclusive, diverse quantum workforce. I will discuss the current status of resources for K-12 learners, educators, and stakeholders, as well as the need to address certain challenges in this ecosystem.

Quantum Computation and Simulation -- Spins Inside

Lieven M.K. Vandersypen
QuTech and Kavli Institute of Nanoscience, Delft University of Technology
l.m.k.vandersypen@tudelft.nl

Quantum computation has captivated the minds of many for almost two decades. For much of that time, it was seen mostly as an extremely interesting scientific problem. In the last few years, we have entered a new phase as the belief has grown that a large-scale quantum computer can actually be built. Quantum bits encoded in the spin state of individual electrons in silicon quantum dot arrays, have emerged as a highly promising direction [1]. In this talk, I will present our vision of a large-scale spin-based quantum processor, and ongoing work to realize this vision.

First, we created local registers of spin qubits with sufficient control that we can program arbitrary sequences of operations, implement simple quantum algorithms [2], and achieve two-qubit gate fidelities of more than 99.5% [3]. In linear quantum dot arrays, we now achieve universal control of up to six qubits [4].

Second, we have explored coherent coupling of spin qubits at a distance via two routes. In the first approach, the electron spins remain in place and our coupled via a microwave photon in a superconducting on-chip resonator. After reaching the strong coupling regime of a single spin and a single photon [5], we have recently observed coherent spin-spin interaction at a distance, mediated by off-resonant photons [6]. In the second approach, spins are shuttled along a quantum dot array, preserving both the spin projection [7] and spin phase [8].

Third, in close collaboration with Intel, we have fabricated and measured quantum dots using all-optical lithography on 300 mm wafer, using industry-standard processing [9], demonstrating excellent qubit performance. We expect that this industrial approach to nanofabrication will be critical for achieving the extremely high yield necessary for devices containing thousands of qubits.

When combined, the progress along these various fronts can lead the way to scalable networks of high-fidelity spin qubit registers for computation and simulation.

[1] L.M.K. Vandersypen, et al., npj Quantum Information **3**, 34 (2017).
[2] T. F. Watson, et al., Nature **555**, 633 (2018).
[3] X. Xue et al., arXiv:2107.00628.
[4] S. Philips, M. Madzik et al, in preparation.
[5] N. Samkharadze, G. Zheng, et al., Science **359**, 1123 (2018).
[6] P. Harvey-Collard, et al, arXiv:2108:01206.
[7] T. A. Baart, et al., Nature Nanotechnology **11**, 330 (2016).
[8] T. Fujita, et al., npj Quantum Information **3**, 22 (2017).
[9] R. Pillarisetty, et al., 2019 IEEE IEDM San Francisco, pp. 31.5.1-31.5.4.
[10] A. M. J. Zwerver, et al., arXiv:2101.12650.

Quantum Computing with Atoms

Christopher Monroe
Duke University and IonQ, Inc.

Trapped atomic ions are a leading physical platform for quantum computers, featuring qubits with essentially infinite idle coherence times. Such atomic clock qubits are controlled with laser beams, allowing densely-connected and reconfigurable universal gate sets. The path to scale involves concrete architectural paths, from shuttling ions between QPU cores to modular photonic interconnects between multiple QPUs. Full-stack ion trap quantum computers have thus moved away from the physics of qubits and gates and toward the engineering of optical control signals, quantum gate compilation for algorithms, software-defined error correction, and high level system design considerations. I will summarize the state-of-the-art in these quantum computers in both academic and industrial settings, and speculate on how they might be used for science and beyond.

Understanding and optimizing silicon/silicon-germanium heterostructures for quantum dot qubits

Susan Coppersmith
University of New South Wales, Australia

Recent progress towards quantum computing in silicon has been impressive, but better understanding of the materials will enable improved controllability and predictability of qubit devices.

This talk will discuss our recent work on characterizing and optimizing silicon/silicon-germanium heterostructures used to host qubits. First, we show that the valley splitting, which is a key property of the band structure in these heterostructures, can be made substantially larger by incorporating Ge in the quantum well which up to now has been made using Si only [1]. Second, we show that understanding the nontrivial interplay between Coulomb interactions and the valley degree of freedom enables one to characterize experimentally the atomic-scale structure of the buried heterostructure interface, and that qubit experiments yield new information about quantum dot properties when interactions are strong [2].

[1] Brian Paquelet Wuetz, Merritt P. Losert, Sebastian Koelling, Lucas E.A. Stehouwer, Anne-Marije J. Zwerver, Stephan G.J. Philips, Mateusz T. Mądzik, Xiao Xue, Guoji Zheng, Mario Lodari, Sergey Amitonov, Nodar Samkharadze, Amir Sammak, Lieven M.K. Vanderspyen, Rajib Rahman, Susan N. Coppersmith, Oussama Moutanabbir, Mark Friesen, and Giordano Scappucci, manuscript in preparation.

[2] J. P. Dodson, H. Ekmel Ercan, J. Corrigan, Merritt Losert, Nathan Holman, Thomas McJunkin, L. F. Edge, Mark Friesen, S. N. Coppersmith, M. A. Eriksson, arXiv:2103.14702.

High-fidelity spin qubit control by electric and magnetic fields

A. Morello
School of Electrical Engineering & Telecommunications, UNSW Sydney, Australia
Email: a.morello@unsw.edu.au

Single-atom electron and nuclear spin qubits in silicon are among the most coherent quantum systems in the solid state [1]. Their embedding within a technologically-relevant, CMOS-compatible physical platform, makes them a prominent candidate for scalable quantum processors [2].

I will describe a 3-qubit electron-nuclear quantum processor, based upon two ion-implanted 31P donors where two nuclei share a common electron. In this system, we have demonstrated 1- and 2-qubit logic gate and state preparation/measurement fidelities all at or above 99%, certified by gate set tomography (GST). The three qubits can be prepared in a maximally entangled Greenberger-Horne-Zeilinger state, with 92.5% fidelity [3].

The above results have been achieved using ordinary magnetic resonance. However, there are potential advantages in being able to control spins by electrical means, since electric fields can be highly localized at the nanoscale, and are easier to screen.
I will present two breakthrough results in the electrical control of spins at the nanoscale. First, the discovery of nuclear electric resonance (NER) in a single 123Sb nuclear spin [4]. NER was obtained through the local modulation of the nuclear quadrupole interaction, mediated by a distortion of the atomic bonds. Second, the coherent control of an electron-nuclear flip-flop qubit, encoded in a single 31P donor atom. The electrical drive is mediated by a local modulation of the hyperfine interaction [5]. Taken together, these results provide a method to achieve complete electrical control over the Hilbert space of a single-atom spin qubit in silicon.

References

[1] J.T. Muhonen *et al*., Nature Nanotech. **9**, 986 (2014)
[2] A. Morello *et al*., Adv. Quant. Tech. **3**, 2000005 (2020)
[3] M. Madzik *et al*., arXiv:2106.03082 (2021)
[3] S. Asaad *et al*., Nature **579**, 205 (2020)
[4] G. Tosi *et al.,* Nature Comm. **8**:450 (2017)

Discovery and Innovation with Quantum Simulation

Travis Humble
Oak Ridge National Laboratory, USA

Among the many advances afforded by quantum information, new methods for modeling and simulation of quantum mechanical systems offer a revolutionary merger between physics and computer science. Chemistry, materials science, high-energy physics, nuclear physics, and many more scientific disciplines benefit from this versatile paradigm to probe the structure and dynamics of quantum matter by accelerating the time-to-solution of simulations and broadening the regime of physical models. Here we highlight leading techniques for quantum simulation including the application to specific domains, the realization with current hardware, and the potential to realize quantum computational advantage. We present on the latest efforts of the Quantum Science Center to integrate these techniques and deliver the next-generation of quantum simulation platforms for empowering scientific discovery and innovation.

Correlated Nanoelectronics and the Second Quantum Revolution

Jeremy Levy
University of Pittsburgh/Pittsburgh Quantum Institute, USA

Strongly correlated electronic materials and quantum transport of nanoelectronic systems are areas of research that have traditionally followed non-intersecting paths. With the development of complex-oxide heterostructures and nanostructures, a nascent field of Correlated Nanoelectronics has emerged. My research program makes extensive use of nanoscale reconfigurability of a complex-oxide heterostructure formed from a thin layer of $LaAlO_3$ grown on $SrTiO_3$. Like an Etch-a-Sketch toy, the $LaAlO_3/SrTiO_3$ interface can be drawn (and erased) with 2 nm resolution to create a remarkable range of quantum devices. These nanoscale devices can be "aimed" back at the materials themselves to provide insight into their inner workings. This platform has already produced two novel phases of electronic matter: one in which electrons form bound pairs without becoming superconducting, and a family of one-dimensional degenerate quantum liquids formed from n-tuples of bound electrons. A rich and growing palette of quantum building blocks are currently being explored for applications in quantum computing, quantum simulation, and quantum sensing, major goals of the Second Quantum Revolution.

Quantum Sensing of Quantum Materials Using NV center Microscopy

Amir Yacoby
Harvard University, USA

The magnetic fields generated by spins and currents provide a unique window into the physics of correlated-electron materials and devices. Proposed only a decade ago, magnetometry based on the electron spin of nitrogen-vacancy (NV) defects in diamond is emerging as a platform that is exceptionally suited for probing condensed matter systems. It can be operated from cryogenic temperatures to above room temperature, has a dynamic range spanning from DC to GHz, and allows sensor-sample distances as small as a few nanometers. As such, NV magnetometry provides access to static and dynamic magnetic and electronic phenomena with nanoscale spatial resolution. While pioneering work focused on proof-of-principle demonstrations of its nanoscale imaging resolution and magnetic field sensitivity, now experiments are starting to probe the correlated-electron physics of magnets and superconductors and to explore the current distributions in low-dimensional materials. In this talk, I will review some of our recent work that uses NV center magnetometry to image skyrmions in thin magnetic films, measure the spin chemical potential in magnetic insulators, and image hydrodynamic electron flow in layered materials. In addition I will describe the use of NV centers in a new scattering platform that uses spin waves as the probing excitation.

Quantum Education at the MS level

Robert Joynt
University of Wisconsin–Madison, USA

Several universities have now started MS programs in Quantum Information Science. The talk will start with what has motivated these efforts, and give a survey of different approaches. It will then move on to a description of the experience we have gained over the past 2+ years of the MS program in Quantum Computing at Wisconsin. The aim is to help others by giving examples of things we got right and things we got wrong.

IBM Quantum Workforce Development Trends and Best Practices

Charles Robinson
IBM, USA

Quantum Information Science (QIS) Workforce Development has emerged as a Science Technology Engineering and Math (STEM) priority at the local, regional, and global level. Here in the United States QIS workforce development has emerged as a priority as highlighted in the National Quantum Initiative and the current US Innovation and Competition Act. There are multiple efforts emerging to provide Quantum information Science education and training by Academia, Industry, and Government. I will discuss a recent survey by the Quantum Economic Development Consortium which polled the Quantum Industry on the workforce needs of the QIS industry. Academia, Industry, and Government stakeholders have expressed the need to find ways to increase Diversity and Inclusion in the Quantum Research landscape. I will discuss ways IBM is addressing this need. Recently there has been an explosion of QIS training and educational programs. In this talk I will discuss some of them, what's working, and best practices and the impact on, K-12, Undergraduate level, Graduate level, and existing workforce education and training. I will highlight what IBM is providing with our partners and clients. Finally, I will discuss how IBM is setting up Quantum Computing access programs and educational partnerships with Academia, Industry, and Government at the local, regional, and national level.

Training the Future Diverse Quantum Workforce: The Need for Pipelines to Ensure Equity and Inclusivity in QISE

Kiera Peltz
Qubit by Qubit, USA

In 2020, Qubit by Qubit, a nonprofit initiative, taught over 10,000 students from 125 countries - ranging from middle school to members of the workforce - quantum computing. In this presentation, Qubit by Qubit's Executive Director, Kiera Peltz, will share what her team has learned about early QISE learners, the need for thoughtful educational pipelines, and policy recommendations.

Anticipating a Semiconductor-Dominated Quantum Future

Jason Petta
Princeton University, USA

The spin state of a single electron can quite naturally be used to encode quantum information. I will review the rapid rise of silicon spin qubits and their potential to disrupt the nascent quantum computing industry.

Spinning qubits from university lab to microelectronics foundry

Ferdinand Kuemmeth
Center for Quantum Devices (QDev), Niels Bohr Institute, University of Copenhagen, Denmark

Our research group is developing spin qubits in two drastically different semiconductors, namely gallium arsenide and silicon. I will introduce the similarities and differences between these material systems, exemplify associated advantages and weaknesses for spin-based quantum applications, and show some of our recent results for controlling individual spins within small two-dimensional arrays of quantum dots.

Engineering qubits in silicon with atomic precision

Michelle Y. Simmons
Silicon Quantum Computing, Sydney, Australia

The realisation of a large-scale error corrected quantum computer relies on our ability to reproducibly manufacture qubits that are fast, highly coherent, controllable and stable. The promise of achieving this in a highly manufacturable platform such as silicon requires a deep understanding of the materials issues that impact device operation. In this talk I will demonstrate our progress to engineer every aspect of device behaviour in atomic qubits in silicon. This will cover the use of atomic precision lithography to achieve fast, controllable exchange coupling, qubit initialisation and read-out; high quality epitaxial growth to create all epitaxial gate structures allowing for highly stable qubits; and unique imaging and modelling techniques that provide a deep understanding of the impact of the solid state environment on qubit designs and operation.

Scientia Professor Michelle Y. Simmons AO FRS, FAA, FAAAS, FTSE, FInstP, Dist FRSN
2018 Australian of the Year
Director, Centre of Excellence for Quantum Computation and Communication Technology
Founder and Director, Silicon Quantum Computing
Chair, American Physical Society Division of Quantum Information
Editor, Nature Quantum Information
Australian Government Laureate Fellow,
School of Physics,
University of New South Wales,
Sydney NSW 2052, AUSTRALIA

Tel: +61-2-9385-6313 (with voicemail)
Fax: +1 815 333 2155
Email: Michelle.Simmons@unsw.edu.au

https://www.physics.unsw.edu.au/staff/michelle-yvonne-simmons
http://www.cqc2t.org/biography/98
https://twitter.com/QuantumC2T

Silicon-based quantum computing:
The path from the laboratory to industrial manufacture

Andrew Dzurak
UNSW, Sydney, Australia

In this talk I will give an overview of the development of silicon-based quantum computing (QC), from the basic science through to its prospects for industrial-scale commercialization based on CMOS manufacturing. I begin with Kane's original proposal [1] for a silicon quantum computer, conceived at UNSW in 1998, based on single donor atoms in silicon, and will review the first demonstrations of such qubits, using both electron spins [2,3] and nuclear spins [4]. I then discuss the development of SiMOS quantum dot qubits, including the demonstration of single-electron occupancy [5], high-fidelity single-qubit gates [6], and the first demonstration of a two-qubit logic gate in silicon [7], together with assessments of silicon qubit fidelities [9,10]. I will also explore the technical issues related to scaling a silicon-CMOS based quantum processor [8] up to the millions of qubits that will be required for fault-tolerant QC, including the recent demonstration of silicon qubit operation above one kelvin [11].

References

[1] B. E. Kane, *Nature* 393, 133 (1998).

[2] A. Morello et al., *Nature* 467, 687 (2010).

[3] J.J. Pla et al., *Nature* 489, 541 (2012).

[4] J.J. Pla et al., *Nature* 496, 334 (2013).

[5] C.H. Yang et al., *Nature Communications* 4, 2069 (2013).

[6] M. Veldhorst et al., *Nature Nanotechnology* 9, 981 (2014).

[7] M. Veldhorst et al., *Nature* 526, 410 (2015).

[8] M. Veldhorst et al., *Nature Communications* 8, 1766 (2017).

[9] H. Yang et al., *Nature Electronics* 2, 151 (2019).

[10] W. Huang et al., *Nature* 569, 532 (2019).

[11] H. Yang et al., *Nature* 580, 350 (2020).

The National Quantum Initiative: Current Status and Perspectives

Charles Tahan
National Quantum Coordination Office, White House Office of Science and Technology Policy/Laboratory for Physical Sciences, USA

Alán Aspuru-Guzik
University of Toronto

Umesh Vazirani
University of California, Berkeley/Berkeley Quantum Computation Center

Orquestra(R): Workflow Management For Quantum Computing

Christopher Savoie
Zapata Computing, USA

To create real value from quantum computers requires deep analysis, rigorous resource assessment, and systematic benchmarking—all which present challenges with extensibility, data management, reproducibility, and framework interoperability. To address these challenges, Zapata developed Orquestra, a workflow-based platform for quantum computing designed from the ground up to be highly extensible and hardware agnostic. In this presentation, Zapata Computing's CEO (and URI alum) Christopher Savoie, PhD, will provide an overview of Orquestra and demonstrate how it is built for extensibility, reproducibility, benchmarking and scaling up experiments—not only for an academic setting, but also in industry.

Quantum Simulation with D-Wave Annealing QPUs

Andrew King
D-Wave Systems, Canada

Quantum annealing is a method of quantum computing that involves tuning a time-dependent quantum system from a disordered quantum superposition state to a low-energy state of a classical system. In D-Wave annealing systems, this requires the physical realization of a transverse field Ising model, which includes many exotic magnetic spin systems. In this talk I will discuss two recent results in quantum simulation with D-Wave annealing QPUs: First, an open-system (finite-temperature) simulation in which a scaling advantage was observed over classical Monte Carlo alternatives. Second, a closed-system simulation of a paradigmatic quantum phase transition in a quantum Ising chain.

Silicon Colour Centres

Stephanie Simmons
Simon Fraser University/Photonic Inc.

The future global quantum internet will require high-performance matter-photon interfaces. The highly demanding technological requirements indicate that the matter-photon interfaces currently under study all have potentially unworkable drawbacks, and there is a global race underway to identify the best possible new alternative. For overwhelming commercial and quantum reasons, silicon is the best possible host for such an interface. Silicon is not only the most developed integrated photonics and electronics platform by far, isotopically purified silicon-28 has also set records for quantum lifetimes at both cryogenic and room temperatures [1]. Despite this, the vast majority of research into photon-spin interfaces has notably focused on visible-wavelength colour centres in other materials. In this talk I will introduce a variety of silicon colour centres and discuss their properties in isotopically purified silicon-28. Some of these centres have zero-phonon optical transitions in the telecommunications bands [2], some have long-lived spins in their ground states [3], and some, including the newly rediscovered T centre, have both [4].

[1] K. Saeedi, S. Simmons, J.Z. Salvail, et al. Science 342:830 (2013).
[2] C. Chartrand, L. Bergeron, K.J. Morse, et al. Phys. Rev. B 98:195201 (2018).
[3] K. Morse, R. Abraham, A. DeAbreu, et al. Science Advances 3:e1700930 (2017).
[4] L. Bergeron, C. Chartrand, A.T.K. Kurkjian, et al. PRXQuantum 1 020301 (2020).

Reducing Gate Errors in IBM Quantum Processors

Emily Pritchett
IBM, USA

I will discuss the current limitations on the gate fidelities of IBM deployed superconducting devices. In addition to reviewing the known errors that limit the performance of quantum gates, I will survey some of the hardware and control innovations that have recently reduced the gate errors demonstrated on fixed frequency transmon qubits, the cornerstone of IBM's quantum processors. An impressive breadth of physics remains at the frontier of large-scale device optimization, a testament to both the richness of superconductor qubits as an architecture for quantum computing and the depth into error characterization the research of the past decade has brought us.

Coherent and Cavity-Based Measurement of Si/SiGe Quantum Dot Qubits

Mark A. Eriksson
Department of Physics, University of Wisconsin-Madison

In this talk I describe two recent advances in the control and measurement of Si/SiGe quantum dot qubits. In the first part of the talk, I describe how Rabi and Ramsey measurements enable spectroscopy of many 2-electron eigenstates in quantum dot qubits. This spectroscopy is enabled by a latched readout technique that requires only one electron reservoir, and the results highlight the critical role played by strong electron-electron interactions in silicon quantum dots. In the second part of this talk I will discuss the use of 3D-integrated resonators for measurement of Si/SiGe quantum dots. Using this technique I will demonstrate the importance and utility of dynamically-driven longitudinal coupling between the resonator and a double quantum dot.

Quantum Engineering of Superconducting Qubits

William D. Oliver
Massachusetts Institute of Technology, USA

Superconducting qubits are coherent artificial atoms assembled from electrical circuit elements and microwave optical components. Their lithographic scalability, compatibility with microwave control, and operability at nanosecond time scales all converge to make the superconducting qubit a highly attractive candidate for the constituent logical elements of a quantum information processor. Over the past decade, spectacular improvements in the manufacturing and control of these devices have moved the superconducting qubit modality from the realm of scientific curiosity to the threshold of technical reality. In this talk, we present recent progress, challenges, and opportunities ahead in the engineering larger scale processors.

Automating quantum computers with artificial intelligence

Michael Biercuk
University of Sydney/Q-CTRL

Hardware instability, inhomogeneities, and crosstalk represent major bottlenecks in the development of quantum computers at scale, typically mandating "manual" device calibration over many control knobs exhibiting uncharacterized coupling and interdependencies. In this talk we will introduce the concept and experimental implementation of AI-driven robust quantum computing hardware optimization and tuneup. We will present a series of experiments on superconducting quantum computers demonstrating the utility of autonomous AI agents for errror-robust gate design, efficient hardware calibration, and fully autonomous gate optimization. Experimental demonstrations begin with noise and crosstalk-robust numerically optimized gates exhibiting up to 10X reductions in error, drift sensitivity, and device variability; we discuss how we autocalibrate these complex waveforms using AI-driven closed-loop runtime optimization, removing the need for standard scripted tuning over multiple (potentially nonlinearly dependent) parameters. Next, we demonstrate the autonomous closed-loop synthesis of optimized SU(3) gates using band-limited Hanning functions, and achieving 99.8% fidelity. We conclude by presenting the first experimental demonstration of Deep Reinforcement Learning (DRL) to autonomously design a Universal gateset in runtime. DRL-designed cross-resonance gates exhibit ~2.5X improvements relative to default pulses, and obviate the need for additional compensating signals designed to mitigate crosstalk. Performance reaches ~99.5% fidelity (near T1 limits) up to 25 days from gate design with no recalibration. In summary, these experiments reveal a pathway to simultaneously improving hardware performance and achieving hardware-level autonomy at scale through applied AI.

Beyond-classical quantum computing

Sergio Boixo
Google, USA

Starting with Google's 2019 Nature publication, there have been several landmark experiments designed to perform computational tasks beyond the reach of state-of-the-art supercomputers. I will review these experiments and the parallel improvement in classical algorithms and approximations. I will also explain some other recent experiments carried out at Google, and conclude with some projections on the expected advances in quantum computing in the next ten years.