INQA

International Network on Quantum Annealing

Conference Agenda

9-11 November 2022 | UCL, London

INQA Conference 2022

Quantum Annealing: Routes to Understanding and Improving Scaling

Quantum annealing is yet to demonstrate the elusive goal of a scaling speedup when benchmarked against classical heuristic optimisers. In this INQA conference we will meet to learn about, consider and discuss possible routes to understanding and improving scaling of QA metrics with system size. Theoretical, numerical and experimental approaches will be discussed. Contributions within this theme or in any other related area of quantum annealing research are welcome.

Members of the INQA management board who helped organise this conference along with the INQA seminar series include:

- Prof Paul Warburton (UCL, UK)
- Dr Pol Forn-Díaz (IFAE, Spain)
- Dr Shiro Kawabata (AIST, Japan)
- Prof Viv Kendon (University of Strathclyde, UK)
- Dr Jamie Kerman (MIT Lincoln Lab, USA)

INQA Conference 2022 Organising Committee:

- Prof Paul Warburton (UCL, UK)
- Shanice Thomas (UCL, UK)
- Henry Chew (UCL, UK)
- Henry Bennie (UCL, UK)

INQA is supported by a International Network Grant from the UK Engineering and Physical Sciences Research Council.

Have a question? Please don't hesitate to contact us.

Venue

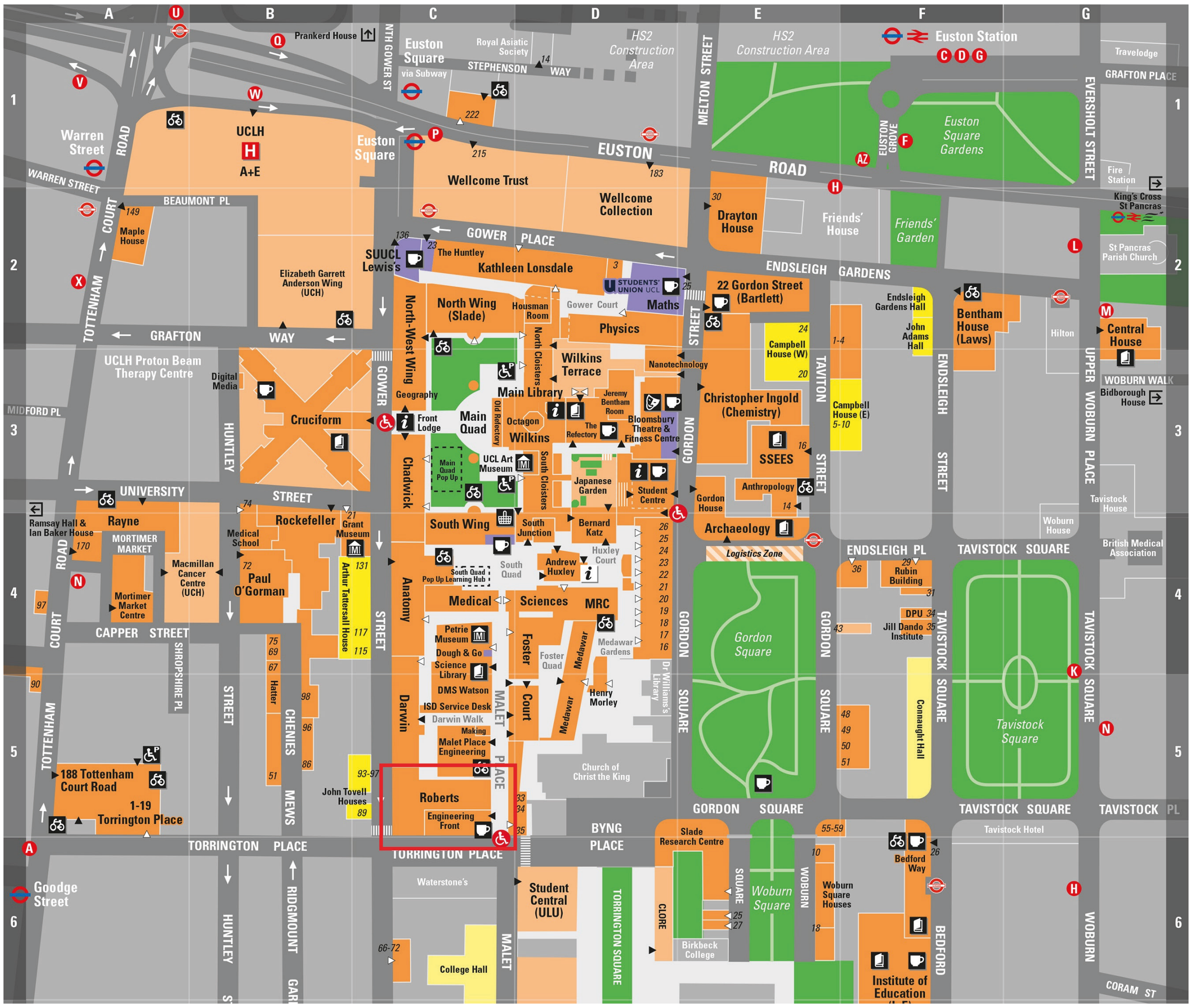
Sir David Davies G08 Lecture Theatre, Roberts Building

University College London

Gower Street

London

WC1E 6BT



Programme

Wednesday 9 November 2022

Coffee and Pastries
09:00 - 09:30

Welcome | Paul Warburton, UCL, UK
09:30 - 09:40

Session 1
09:45 - 10:30

Fast tunneling of frozen chains using AC drives and tone synchronization | Eliot Kapit, Colorado School of Mines, USA

To enable arbitrary-ranged logical interactions in locally connected quantum processors, embedding schemes are required, where single logical variables are encoded as long ferromagnetic chains. Variants of this scheme can also be used to suppress thermal and control errors, through a collection of methods called Quantum Annealing Correction. However, this comes at a cost, as once a chain transitions to the ferromagnetic phase--"freezes"--its tunneling rate from one state to the other is exponentially suppressed in the length of the chain. This leads to ugly tradeoffs in choosing the chain strength, and severe performance penalties. In this talk, we simulate this problem with the addition of RFQA, a strategy where local AC oscillations are applied to every qubit, accelerating multiqubit tunneling. In this talk, we consider how the knowledge that all spins in a chain must flip at once--even if we do not know which chains must flip in any given problem--can be used to further accelerate tunneling by synchronizing tones within a chain. We show dramatic advantages from this technique, over both uniform fields and random tone distributions. Further, tone synchronization allows fewer unique frequencies to be applied, reducing the control overhead and improving the prospects for implementation in large processors.

Session 2
10:30 - 11:15

Using quantum annealers for brief periods of time | Juanjo Jośe García-Ripoll, CSIC, Spain

QAOA or Quantum Approximate Optimization Algorithm is a quantum algorithm inspired in adiabatic quantum computation, which combines evolution with a problem Hamiltonian (an Ising model) and local operations on the qubits that implement it. In this talk I discuss what happens when we have access to a quantum annealer or quantum simulator and use it to implement a single-layer QAOA circuit (See P. Díez et al, https://arxiv.org/abs/2201.03358). The focus is not so much on the optimization, but on the types of states that are created. We show that a brief evolution with the quantum simulator, interspersed with local gates, implements a many-body interferometer in energy space, creating pure states that resemble Boltzmann distributions with remarkably low temperature. I discuss how this dynamics is very different form conventional termalization and is instead explained by a hidden correlation in the underlying spin model.

Coffee
11:15 - 11:45

Session 3
11:45 - 12:30

Application specific annealers: a case study for Fermi-Hubbard annealers | Filip Wudarski, USRA, USA

Quantum annealers have been broadly studied in the context of combinatorial optimization problems onto which you can map a host of interesting problems ranging from traffic optimization to machine learning. However, these annealers are not universal, and fail to exploit the full power of quantum computing. Therefore, in this talk, we will present an alternative look at annealing that is tailored to solve a different class of problems, namely Fermi-Hubbard models (FHMs). FHMs are proxy models for material simulations that allow us to study phenomena such as superconductivity or insulating phases. The problem Hamiltonians (given in second quantization) first need to be mapped to the qubit structure, which we achieve by employing a low-weight encoding requiring at most 3-local interactions. We design an annealing protocol that is investigated numerically and provides promising results for spinless and spinful systems. Additionally, we will present experimental perspectives for the proposed design and compare the number of resources required to solve the same problems with a gate based quantum computers and Fermi-Hubbard Annealers. Finally, we will discuss obstacles related to noise, state preparation, measurements and discuss potential solution to those problems.

Session 4
12:30 - 13:15

Quantum Annealing: From theory to practice | Nick Chancellor, University of Durham, UK

In this talk I will discuss some of the challenges in getting quantum annealing into practice and how theoretical efforts can support this, highlighting recent results from my group which support this effort. To start with, I will discuss the need to obtain understanding beyond the adiabatic regime, which while highly conducive to theory, is difficult to reach with hardware, I will highlight recent efforts to understand different mechanisms which operate far from the adiabatic limit as discussed in [Callison et. al. PRX Quantum 2, 010338 (2021)]. Next I will briefly discuss encoding and algorithms, reviewing reverese annealing and related tools for developing hybrid algorithms in quantum annealing, and work showing the effect of having optimal encoding schemes, as well as furture directions along these lines. Finally, I will discuss efforts to find uses for quantum annealing within an academic context, using recent work at Durham on applying quantum annealing to assist partitioning in large simulations.

Lunch
13:15 - 14:30

Session 5
14:30 - 14:52

A graph-theoretical analysis on first order quantum phase transitions for adiabatic quantum computing | Matthias Werner, Qilimanjaro, Spain

In the context of adiabatic quantum computation (AQC), it has been argued that first order quantum phase transitions (QPTs) due to localisation phenomena will cause AQC to fail by (super-)exponentially decreasing the minimal spectral gap of the Hamiltonian along the annealing path. The vanishing spectral gap occurs due to localisation of the ground state in a local minimum, requiring the system to tunnel into the global minimum at a later stage of the annealing. However this notion has been subject to some debate in the community, since more recent findings suggest the existence of methods to avoid this by carefully designing the involved Hamiltonians. It remains a challenge to formulate a comprehensive theory on the effect of the various parameters and the conditions under which QPTs make the AQC algorithm fail. In this work we investigate the conditions under which localisation causes first order QPTs using spectral graph theory, examine both analytically and numerically the role of the connectivity of the driver Hamiltonian in the mitigation of such effects in different AQC algorithms and derive bounds on the location of the minimal spectral gap along the anneal path. We apply the developed theory to investigate the impact of generic catalyst Hamiltonians on the existence of first order QPTs. The results suggest that stoquastic catalyst decrease the chance of observing a first order QPT on a random problem instance, while non-stoquastic catalyst seem to have the opposite effect. Our analysis augments the tool box to design the driver and catalyst such that first order QPTs are avoided and the runtime of AQC algorithms is improved.

Session 6
14:52 - 15:14

Rapid quantum approximate solvers for combinatorial optimisation problems inspired by Hamiltonians for optimal state-transfer | Bobby Banks, UCL, UK

Much of quantum annealing is motivated by adiabatic quantum optimisation. Here we suggest a new design heuristic to tackle combinatorial optimisation problems, inspired by Hamiltonians for optimal state-transfer. The result is a rapid approximate optimisation algorithm. We provide numerical evidence of the success of this new design heuristic. We find this new approach gives a better approximation ratio than the Quantum Approximate Optimisation Algorithm at lowest depth on the majority of problem instances considered, while utilising comparable resources. This opens the door to investigating new approaches for tackling combinatorial optimisation problems, away from adiabatic inspired approaches.techniques, including shortcuts to adiabaticity by counter-diabatic driving, their combination with variational approaches, and local inhomogeneous controls.

Tea

15:14 - 15:45

Session 7

15:45 - 16:30

Effects of targeted XX-catalysts on quantum annealing spectra with perturbative crossings | Natasha Feinstein, UCL, UK

The efficiency of Adiabatic Quantum Annealing is limited by the scaling with system size of the minimum gap between the ground and first excited states in the annealing energy spectrum. In particular, competing local optima can result in so-called perturbative crossings which produce exponentially closing gaps in the annealing spectrum. One promising avenue being explored to circumvent this bottleneck is the introduction of catalyst Hamiltonians which change the annealing path. Of particular interest are catalysts which utilise accessible information about the optimisation problem in their construction. Here we show extreme sensitivity of the effect of a targeted non-stoquastic XX-catalyst to subtle changes in the encoding of the optimisation problem. In particular, we observe that a catalyst containing a single coupling at constant strength can significantly reduce the gap closing with system size at a perturbative crossing under certain conditions. For slightly different encodings of the same problems however, these same catalysts result in closing gaps in the annealing spectrum. Studying the closed-system dynamics, we find that the catalyst is able to enhance the final ground state overlap in both settings. In the first case this is achieved by making the adiabatic limit more accessible; in the second case by creating a path through the spectrum that can be exploited in a diabatic annealing protocol.

Session 8

16:30 - 17:15

Analysis on gaps, encodings and hybrid approaches at Qilimanjaro | Ana Palacios, Qilimanjaro, Spain

Qilimanjaro is a full-stack start-up company working on the development of coherent quantum annealers based on superconducting quantum circuits. In this talk, we will cover a selection of the ongoing projects of Qilimanjaro's theory team, which range from encoding techniques to reduce the number of resources required for solving a problem in quantum hardware, to the development of more fundamental tools to understand the evolution of the gap during an annealing process. We will also present an overview of some of the currently explored hybrid strategies beyond the analogue paradigm, such as the combination of digital and analogue elements to complement the lack of connectivity and interactions of the hardware, as well as the use of subparts of the chip as auxiliary systems to aid in the annealing computation in the context of quantum reservoirs and quantum probes.

Reception

17:15

Thursday 10 November 2022

Coffee and Pastries

09:00 - 09:30

Session 1

09:30 - 10:15

Counterdiabatic rotated ansatz for many-body systems | Glen Mbeng, University of Innsbruck, Austria

Counterdiabatic (CD) drivings are promising tools to enhance quantum adiabatic processes allowing a faster manipulation of quantum systems. However, implementing CD protocols entails the introduction of additional control fields in the Hamiltonian, often associated with highly non-local multi-body interactions. We will introduce a novel variational rotated ansatz (RA) to generate experimentally accessible approximate CD protocols. We will present and numerically benchmark the RA protocols for (i) a two-level system, (ii) a non-integrable Ising chain, and (iii) programmable quantum annealing architectures. Lastly, we will introduce the concept of multiple RA iterations and present preliminary numerical simulations for the non-integrable Ising chain, illustrating the potential benefits of reiterating the RA approach.

Session 2

10:15 - 11:00

Applications on quantum annealers at FZJ | Dennis Willsch, FZ-Jülich, Germany

Quantum annealing is a new computer technology that gradually becomes ready to tackle small real-world applications. In this talk, I will give an overview of recent applications that we studied on the currently largest quantum annealers, the 5000+ qubit quantum annealer Advantage and its 2000+ qubit predecessor D-Wave 2000Q. The applications contain (1) vegetable garden optimization, (2) exact cover problems for airline scheduling, (3) the traveling salesman problem, (4) hard 2SAT problems, (5) quantum support vector machines for applications in computational biology and remote sensing, and (6) quantum Boltzmann machines with applications in quantitative finance. All problems serve as benchmarks to measure progress but also limitations of the current generation of quantum computers.

Coffee

11:00 - 11:30

Session 3

11:30 - 11:52

Accreditation of analogue simulators | Theo Kapourniotis, University of Warwick, UK

Quantum simulation is rapidly emerging as a leading quantum technology. Whilst digital quantum computing can efficiently simulate quantum systems, analogue quantum simulators tend to be larger and less error-prone than their digital contemporaries. But for digital devices, verification is a well studied problem. Analogue quantum simulators, on the other hand, have thus far eluded scalable verification methods. The prevalent methods for checking the results of an analogue simulator are built around classical simulation. However, the purpose of developing such a simulator is to simulate classically intractable systems. Hence, classical simulation based verification methods will fail in the domain of most interest. So new approaches are required.

We present an accreditation protocol for analogue (continuous-time) quantum simulations. Our protocol can bound the variational distance between the ideal and experimentally obtained probability distributions of the measurement outcomes. We believe this to be the first such protocol and it does not require extensive classical computation or increase the target simulation size.

Session 4

11:52 - 12:14

Constrained optimization on quantum annealers using linear penalty functions | Puya Mirkarimi, University of Durham, UK

Real-world combinatorial optimization problems often involve many constraints. In quantum annealing, constraints that are linear in the input variables are typically encoded by adding quadratic penalty functions to the problem's objective function in order to penalise infeasible solutions. The addition of these quadratic terms reduces the available dynamic range of qubit interactions and may increase the total number of qubit interactions that need to be implemented. Using a problem in customer data science as an example, we explore an alternative penalty method involving only linear terms, which can be applied to QUBO problems with only non-negative quadratic terms in the objective function and avoids some of the drawbacks of the standard quadratic penalty method.

Session 5
12:14 - 12:36

Adiabatic quantum computing with parameterized quantum circuits | Ioannis Kolotouros, University of Edinburgh, UK

In order to mitigate the limitations of NISQ devices, a number of hybrid approaches have been pursued in which a parameterized quantum circuit prepares and measures quantum states and a classical optimization algorithm minimizes an objective function that encompasses the solution to the problem of interest. In our work, we propose a different approach starting by analyzing how a small perturbation of a Hamiltonian affects the parameters that minimize the energy within a family of parameterized quantum states. We derive a set of equations that allow us to compute the new minimum by solving a linear system of equations obtained by measuring a series of observables on the unperturbed system. We then propose a discrete version of adiabatic quantum computing which can be implemented with quantum devices identical to those of variational quantum algorithms, while being insensitive to the parameter initialization and other limitations that the optimization part of variational quantum algorithms bring. Finally, we test the performance of our algorithm in both noisy and noiseless environments, solving a classical optimization problem and a quantum-spin problem. We observe that our method is able to achieve near-optimal solutions on both the Max-Cut for 3-regular graphs as well in random Transverse-Ising Chain models.

Lunch
12:36 - 14:00

Session 6
14:00 - 14:45

Coherent quantum annealing and quantum critical spin-glass dynamics | Andrew King, D-Wave, Canada

Quantum annealing was motivated in part by evidence from magnetism experiments that quantum fluctuations could bring spin glasses into low-energy states faster than thermal fluctuations. Reproducing this phenomenon in a programmable system has been a central goal of the field for over twenty years. Here we reproduce this goal by realizing quantum critical spin-glass dynamics on thousands of qubits with a superconducting quantum annealer. We first demonstrate quantitative agreement between quantum annealing and time-evolution of the Schrödinger equation in small spin glasses. We then measure dynamics in 3D spin glasses on thousands of qubits, where simulation of many-body quantum dynamics is intractable. We extract critical exponents that clearly distinguish quantum annealing from the slower stochastic dynamics of analogous Monte Carlo algorithms. A generalized Kibble-Zurek formalism for dynamics in the critical region provides a theoretical basis for the observed speedup.

Session 7

14:45 - 15:30

Superconducting quantum annealer based on application specific architecture | Shiro Kawabata, AIST, Japan

Quantum annealing is a promising technique which leverages quantum mechanics to solve hard combinatorial optimization problems [1]. D-Wave Systems Inc. is the first company to commercialize superconducting quantum annealing machine in 2011 and will ship a new machine with +7000 qubits in 2023. However, integration of larger number of qubits as well as improvement of qubit coherence are required for practical applications. In this talk we will overview our technological integration scheme for large-scale superconducting quantum annealing machine in AIST [2-6]. The scalability is achieved by QUIP (QUbit, Interposer and Package substrate) structure, which is based on our multi-layer fabrication and multi-chip 2.5D packaging technology such as Through Silicon Via (TSV) and flip-chip bonding. We have also developed an Application Specific Annealing Computing (ASAC) architecture in order to increase the available hardware budget and reduces the cost and time for R&D. In addition, we will show a fabricated quantum annealer AQUA1.1 (6 Nb flux qubits) for prime factoring [3], experimental results of a 3-6 qubits quantum annealers at 10mK [3-5], and numerical simulation for 2.5D integrated quantum annealer [6].

Tea

15:30 - 16:00

Session 8

16:00 - 16:45

AVaQus project progress | Pol Forn-Díaz, IFAE, Spain

Analog quantum processors hold a high potential to show quantum advantage in the near future. These systems may be programmed to operate as quantum annealers to address optimisation problems, as well as variational quantum algorithms and quantum simulations. The technology to build coherent analog quantum processors is still in a premature stage and requires dedicated efforts to be able to scale up into large-scale processors to address real-world problems.

The AVaQus (Annealing-Based Variational Quantum Processors) program is the largest-scale European effort to develop the technology and functionality to operate analog quantum processors as coherent quantum annealers and variational processors. The focus of the project is on both the hardware as well as the theoretical sides, to yield a small-scale prototype representing the unit cell of a larger-scale processor that will succeed project AVaQus in the future. The project kicked off in the fall of 2020, and has recently completed the first of its three phases.

In this talk, I will report on the current state of project AVAQus, focusing on the most recent developments as well as the upcoming challenges. In particular, I will describe the multi-qubit readout technology, the current state of coherent qubit device fabrication and the latest theory developments on qubit-qubit couplings and quantum algorithms.

Friday 11 November 2022

Coffee and Pastries
09:00 - 09:30

Session 1
09:30 - 10:15

Navigating Equality, Diversity and Inclusion in the Changing Tides of Quantum Technologies | Abbie Bray, UCL, UK

“Navigating” EDI in Quantum Technologies is an introductory talk on the pillars of EDI, particularly target at those who work, recruit and study in a STEM and particularly a Quantum field. The talk will explore what is EDI, how we can make effective change and the pitfalls of some EDI initiatives in our community. We start by exploring how intersectionality is vital for progress then we move onto self-assessment: how does your STEM environment champion diversity and inclusivity? Here, we discuss the issues of stagnation and complacency that can happen within institutions. We end by summarizing small steps that can help establish effective change and look forward to a more inclusive community.

Session 2
10:15 - 11:00

Shortcuts in quantum annealing | Adolfo Del Campo, University of Luxembourg, Luxembourg

I will review complementary efforts to assist quantum annealing by a variety of techniques, including shortcuts to adiabaticity by counter-diabatic driving, their combination with variational approaches, and local inhomogeneous controls.

Coffee
11:00 - 11:30

Session 3
11:30 - 12:15

Error Mitigation for Quantum Approximate Optimization | Anita Weidinger, University of Innsbruck, Austria

Solving industrial relevant optimization problems on near term quantum devices, requires developing error mitigation techniques to cope with hardware decoherence and dephasing processes. In this work we propose a mitigation technique based on the LHZ architecture. This architecture uses a redundant encoding of logical variables, to solve optimization problems on fully programmable planar quantum chips. We discuss how this redundancy can be exploited to mitigate errors in quantum optimization algorithms. In the specific context of approximate optimization algorithm (QAOA), we show that errors can be significantly mitigated by appropriately modifying the objective cost function.

Session 4
12:15 - 13:00

Using copies to improve precision in continuous-time quantum computing | Jemma Bennett, University of Durham, UK

In the quantum optimisation setting, we build on a scheme introduced by Young et al [PRA 88, 062314, 2013], where physical qubits in multiple copies of a problem encoded into an Ising spin Hamiltonian are linked together to increase the logical system's robustness to error. We introduce several innovations that improve this scheme significantly. First, we note that only one copy needs to be correct by the end of the computation, since solution quality can be checked efficiently. Second, we find that ferromagnetic links do not generally help in this "one correct copy" setting, but anti-ferromagnetic links do help on average, by suppressing the chance of the same error being present on all of the copies. Third, we find that minimum-strength anti-ferromagnetic links perform best, by counteracting the spin-flips induced by the errors. We have numerically tested our innovations on small instances of spin glasses from Callison et al [NJP 21, 123022, 2019], and we find improved error tolerance for three or more copies in configurations that include frustration. Interpreted as an effective precision increase, we obtain several extra bits of precision for three copies connected in a triangle. This provides proof-of-concept of a method for scaling quantum annealing beyond the precision limits of hardware, a step towards fault tolerance in this setting.

Lunch
13:00 - 14:15

Session 5
14:15 - 15:00

Engineering challenges in quantum annealing using Kerr-parametric oscillators | Aiko Yamaguchi, NEC, Japan

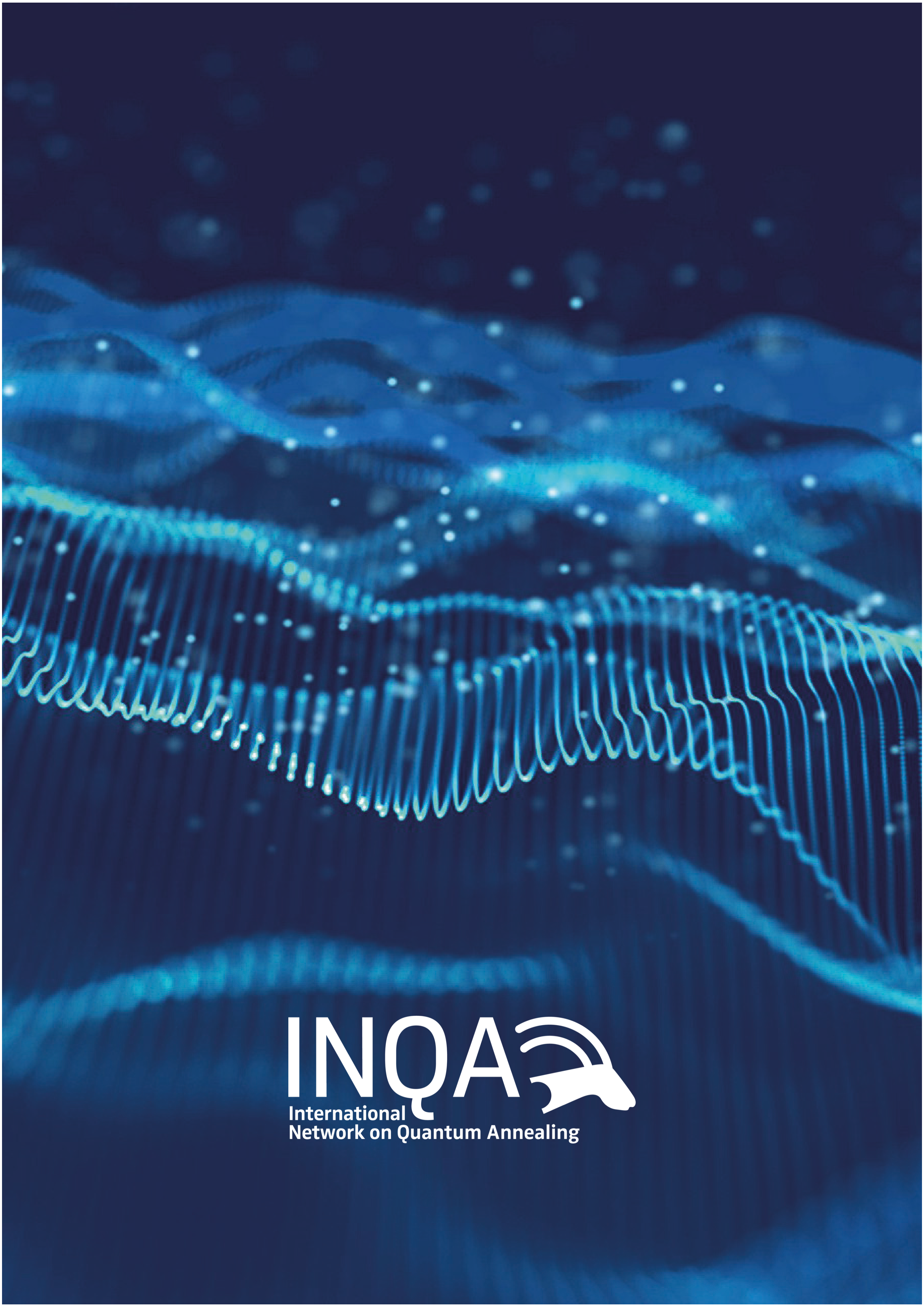
Kerr-parametric oscillator (KPO) is one of the promising candidates for a building block of quantum annealing machine. We are developing all-to-all-connected quantum annealing machine based on LHZ scheme with KPOs. Although theoretical proposals have been made, there are engineering challenges in realizing the quantum annealing machine. These challenges include calibration method for the amplitudes of coherent drive and parametric drive for the KPO, realization of couplings between KPOs, and establishment of three-dimensional wiring structure. In this talk, I will discuss our recent work on these challenges. This work is based on results obtained from a Project, Project No. JPNP16007, commissioned by the New Energy and Industrial Technology Development Organization (NEDO). This work was partly supported by JST Moonshot R&D (JPMJMS2062).

Session 6
15:00 - 15:45

Landau-Zener tunneling: from weak to strong environment coupling | Adrian Lupascu, University of Waterloo, Canada

Landau-Zener tunneling, which describes the transitions in a two-level system during a sweep through an anti-crossing, is a model applicable to a wide range of physical phenomena. Dissipation due to coupling between the system and environment is an important factor in determining the transition rates. Using a tunable superconducting flux qubit, we observe the crossover from weak to strong coupling to the environment. The weak coupling limit corresponds to small system-environment coupling and leads to environment-induced thermalization. In the strong coupling limit, environmental excitations dress the system and transitions occur between the dressed states. Our results confirm previous theoretical studies of dissipative Landau-Zener tunneling in the weak and strong coupling limits, and motivate further work on understanding the intermediate regime. This work is relevant for understanding the role of open system effects on quantum annealing.

Tea
15:45


INQA
International
Network on Quantum Annealing