QUANTUM SIMULATIONS AND ALGORITHMS WITH SUPERCONDUCTING CIRCUITS

KFAR BLUM, ISRAEL, 11-15.09.2022

ABSTRACT BOOKLET

2022

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09:00-09:35	Bus: Jerusalem (departs 9:30) Ramat Gan (departs 10:00)	Silva	Briegel	Demler	Room check-out
09:35-10:10		Ivry	Hacohen-Gourgy	Cohen	Uzdin
10:10-10:45		Tafuri	Makmal	Sela	Pick
10:45-11:15		Coffee break	Coffee break	Coffee break	Coffee break
11:15-11:50		Panigrahi	Landa	Rosenblum	Katz
11:50-12:25		Illuminati	Naveh	Dupont	Dalla Torre
12:25-13:00	Registration	Bar-Gill	Manzano Diosdado	Zohar	Lunch and bus departure at 14:00
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14:30-15:05	Avron	Ozeri	Retzker	Lindner	
15:05-15:40	Citro	Oliver	Guerreschi	Kotler	
15:40-16:00	Salhov	Frankel	Guarcello	Burshtein	
16:00-16:20	Brodutch		Maskil, Tauber	Oviedo-Casado	
16:20-16:50	Coffee break	Coffee break	Coffee break	Coffee break	
16:50-17:25	Stern	Paladino	Poster session and round table with Reinhold Cohn Group	Kurizki	
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19:00-20:00	Dinner & Welcome event ("Opera room")	Dinner	Dinner and night trip to Nimrod Fortress	Dinner and Prize Winners announcement	

Day I: Sunday

Lindblad evolutions, conservation laws and Born rule

Yosi Avron
Technion

We discuss an apparent theoretical difficulty in applying the Born rule to the radiation emitted by a system undergoing Lindblad evolution. The difficulty is resolved by identifying the measurement of radiation with the Born rule for a conserved current. The current operator is determined by the action of the adjoint Lindbladian on the conserved quantity. (Based on arXiv:2203.14634)

Quantum phase batteries and pumps

Roberta Citro
University of Salerno

The access to quantum physics at nanoscale has revolutionized our daily life opening the way to quantum computing, quantum information and novel forms of energy harvesting. In particular, batteries and pumps are ubiquitous in our everyday lives, with lithium-ion batteries being the most commonly used type — though interesting alternatives are, in fact, in development. The quantum phase battery is a different beast altogether. While classical batteries convert chemical energy into voltage, which powers electronic circuits, quantum technologies use circuits or devices based on superconducting materials or nanostructures. In superconducting materials, currents flow without the need for an applied voltage. Therefore, when it comes to quantum computers, there is no need for a classical battery. Supercurrents get their name from the fact that they do not exhibit any energy losses. They are induced from a phase difference of the wave function of the quantum circuit, rather than from a voltage. Similarly, in a quantum pump the current flows without the need for an applied voltage. It is from the geometric phase of the quantum systems that is varied slowly in time[1]. This means that a quantum device able to provide a persistent phase difference can be seen as a quantum phase battery, which induces supercurrents in a quantum circuit. We discuss here the realization of a quantum phase battery based on InAs nanowires, where the interplay between spin-orbit coupling and exchange interaction induces a break of the phase rigidity of the system and produce a phase battery[2], a topological quantum pump realized in quasiperiod optical lattice where a current is generated by Berry phase effects[3] and various quantum pumps in nanostructures, like quantum dots.

[1] R. Citro, "Ultracold atoms: A topological charge pump", Nature Physics 12, 288 (2016)
[2] E. Stramini et al. "A Josephson phase battery", Nature Nanotechnology (2020) 10.1038/s41565-020-0712-7
[3] C. Schweizer, M. Lohse, R. Citro, I. Bloch, Phys. Rev. Lett. 117, 170405 (2016)

Short Talk: Dynamical Decoupling via Destructive Interference

Alon Salhov
The Hebrew University of Jerusalem

Coherence loss is one of the main challenges to implementing quantum information processing. The efficiency of dynamical decoupling (DD) schemes, which have been introduced to address this problem, is limited by the noisy fluctuations in the driving fields. As the central idea of DD is refocusing of environmental and control fluctuations, it is effective when the quantum system can be manipulated faster than the correlation time of the noise. In my talk, I will present a DD principle that is complementary to that of refocusing, namely, destructive interference of correlated fluctuations. Such correlations are expected to exist when two or more control fields originate from the same physical source. Our protocol prolongs the coherence time by more than an order of magnitude in simulations and three-fold in experiments with the Nitrogen-Vacancy center in diamond. Moreover, we show a two-fold improvement in the coupling of the qubit to external fields and a 20 percent improvement in its internal frequency, which are beneficial for quantum gates and sensing. Finally, we show some examples of robust single qubit operations with a different scheme that is similarly based on the destructive interference concept. The proposed schemes can be used for quantum sensing and computing in most qubit-based physical systems, such as superconducting qubits, quantum dots, and trapped atoms and ions.

Short Talk: Multi-QPU quantum computation and optical quantum interconnects

Aharon Brodutch
Entangled Networks Ltd.

Quantum computers are extremely difficult to scale up due to issues with noise, cooling, control, testing and manufacturing that become more difficult as the number of qubits increases. The most reasonable way to scale up to the millions of qubits required for error correction is to use a modular architecture made up of multiple quantum processing units (QPUs) that can exchange quantum information. Quantum interconnects are the physical devices used to create an inter-QPU quantum communication channel but present an overhead in terms of computational speed. These overheads can be reduced by designing better hardware and by reducing the number of times the interconnects are used during the computation. We will present results showing how software optimization methods can be used to make interconnects viable even in the case where inter-QPU operations are an order of magnitude slower than intra-QPU operations.

Reproducibility and control of superconducting flux qubits

Michael Stern
Bar Ilan University

Superconducting flux qubits are good candidates for the physical realization of a scalable quantum processor. Indeed, these circuits may have both a small decoherence rate and a large anharmonicity. These properties enable the application of fast quantum gates with high fidelity and significantly reduce the limits to scaling. The major difficulty of flux qubits' design consists of controlling precisely their transition energy - the so-called qubit gap- while keeping long and reproducible relaxation times. Solving this problem requires an extremely good control of e-beam lithography, oxidation parameters of the junctions and sample surface and has not been solved so far. Here we present measurements of a large batch of flux qubits and demonstrate an unprecedented level of control of qubit gaps and relaxation times. This reproducibility enabled us to analyze the different factors that influence the dephasing of the qubits and opens the way for potential applications in the fields of quantum hybrid circuits and quantum computation.

Simulating non-Hermitian systems on superconducting quantum processors

Gheorghe-Sorin Paraoanu
Aalto University

The observation of genuine quantum effects in systems governed by non-Hermitian Hamiltonians has been an outstanding challenge. I will present a method for simulating the evolution under such Hamiltonians on a superconducting quantum processor, by using a dilation procedure involving an ancillary qubit. We observe the parity–time (PT)-symmetry breaking phase transition at the exceptional points and extract the critical exponent, and we show that this transition is associated with a loss of state distinguishability. In a two-qubit setting we demonstrate that the entanglement can be modified by local operations.

Positivity Constraints For Periodically Driven Quantum System

Tanmoy Pandit
The Hebrew University of Jerusalem

Diagnostic the quantum circuits are difficult but at the same time, it is crucial. We construct the positive operator in Liouville space and find some constrain in Liouville space which is applicable to an isolated quantum system. We use positivity in Liouville space to show that these inequalities satisfy an exponential decay law as the number of cycles increases. Consequently, these inequalities are exponentially close to equalities. It is demonstrated that the deviation from exponential scaling is an indication of the non-ideality of devices even when no inequality is violated. Using the positivity approach we explain the previously observed monotonic decrease feature of these constraints and provide an explicit expression for the coefficients of inequality. Finally, we demonstrated our findings in the IBM quantum computer and trapped ion quantum computer.

Day II: Monday

Quantum simulators and Many-Body Quantum Chaos

Alessandro Silva
SISSA

Recently the study of quantum chaos became the subject of renewed interest in the context of quantum many-body physics. In this talk I will focus on describing various characterisations of chaos in spin chains which could be simulated by superconducting circuits. In particular I will focus on out-of-time order correlations, thermalisation and quantum scars and discuss in detail how to observe their physics.

Nonvolatile Voltage-tunable Ferroelectric-superconducting Quantum Interference Memory Devices

Yachin Ivry
Technion

Superconductivity is a prominent platform in the race for quantum technologies thanks to the shared quantum state of electrons over a device-relevant lengthscale. Nevertheless, processing and storing information in the quantum realm with superconductors is a challenging task. That is, while the lack of electric resistance in superconductors is advantageous for low-power applications, following Ohm's low, it entails also inability to apply local gate voltage, e.g., as in semiconducting transistors. Consequently, superconducting quantum devices are operated with magnetic fields and RF signals, both impose a large device footprint, hindering device scalability and system integration at the restricting cryogenic ambient. We introduced voltage-gated quantum devices by placing the superconductor in a close proximity to ferroelectric materials, which are known as excellent insulators with high dielectric constant and polarization storage. The hysteretic polarization-voltage profile of the ferroelectrics was utilized to demonstrate voltage-dependent information storage in a superconducting quantum interference device.

[1] Suleiman et al. Applied Physics Letters 119 112601 (2021).

Hybrid Josephson Junctions, opportunity for quantum hardware

Francesco Tafuri
University of Napoli

Progress in material science and nanofabrication gives opportunities to create unique hybrids Josephson junctions (JJs) which can be smartly integrated into classical and quantum architectures and even with other quantum platforms, also promoting alternative control and read-out schemes in superconducting qubits.

We will report on special properties of hybrid JJs which make possible alternative layouts for the superconducting quantum modules[1,2,3], and on a Single Flux Quantum SFQ-compatible approach to accomplish diabatic readout of superconducting qubits based on a Josephson Digital Phase Detector (JDPD)[4]. We classify some significant behaviors of unconventional junctions through a comparative study of fluctuations and of electro-dynamical properties with a special focus on ferromagnetic Josephson junctions. The competition between superconducting and ferromagnetic orderings in Josephson devices has promoted fundamental and applicative studies of high impact for superconducting digital technology, cryogenic memories, and spintronics, where the possibility of switching between different magnetic states is a crucial advantage[1,3]. Very high-quality tunnel ferromagnetic Al-based JJs have been realized paving the way for the possible implementation of Al tunnel ferromagnetic JJs in superconducting quantum circuits2, toward alternative approaches based on digital control of the JJ. As far as JDPD are concerned, when properly excited by an external flux, the JDPD is able to quickly switch from a single-minima to a double-minima potential and, consequently, relax in one of the two stable configurations discriminating between two phase values of a coherent input tone at GHz frequency[4]. We finally discuss how to exploit currently available tunnel ferromagnetic Josephson junctions to realize a hybrid superconducting qubit[3], where the characteristic hysteretic behavior of the ferromagnetic barrier provides an alternative and intrinsically digital tuning of the qubit frequency by means of magnetic field pulses.

1) Coexistence and tuning of spin-singlet and triplet transport in spin-filter Josephson junctions, H. G. Ahmad, M. Minutillo, R. Capecelatro, A. Pal, R. Caruso, G.Passarelli, M. G. Blamire, F. Tafuri, P. Lucignano and D. Massarotti, Communications Physics 5, 2 (2022); Tuning of magnetic activity in spin-filter Josephson junctions towards spin-triplet transport, R. Caruso, D. Massarotti, G. Campagnano, A. Pal, H. G. Ahmad, P. Lucignano, M. Eschrig, M. G. Blamire, and F. Tafuri, Phys. Rev. Lett. 122, 047002 (2019); RF assisted switching in magnetic Josephson junctions, R. Caruso, D. Massarotti, V.V. Bol'ginov, A. Ben Hamida, L.N. Karelina, A. Miano, I.V. Vernik, F. Tafuri, V.V. Ryazanov, O.A. Mukhanov, and G.P. Pepe, Jour. Appl. Phys. 123, 133901 (2018)

2) Aluminum-ferromagnetic Josephson tunnel junctions for high quality magnetic switching devices, A. Vettoliere, R. Satariano, R. Ferraiuolo, L. Di Palma, H. G. Ahmad, G. Ausanio, G. P. Pepe, F. Tafuri, D. Montemurro, C. Granata, L. Parlato, and D. Massarotti, Appl. Phys. Lett. 120, 262601 (2022)

3) A hybrid ferromagnetic transmon qubit: circuit design, feasibility and detection, H.G. Ahmad, V. Brosco, A. Miano, L. Di Palma, M. Arzeo, D. Montemurro, P. Lucignano, G.P. Pepe, F. Tafuri, R. Fazio, and D. Massarotti, Phys. Rev. B 105, 214522 (2022)

4) Discriminating the phase of a weak coherent tone with a flux-switchable superconducting circuit, L. Di Palma, A. Miano, P. Mastrovito, M. Arzeo, D. Massarotti, D. Montemurro, G. P. Pepe, F. Tafuri and O.A. Mukhanov , in preparation (2022)

Designing information-theoretically secure and fully quantum blockchain protocols

Prasanta Panigrahi
IISER Koltaka

The transparency and accountability feature of blockchain makes it appealing to a wide range of applications. It, therefore, has attracted significant attention from the research community. In the age of quantum computers, however, blockchain architectures are at risk of losing their security. For this reason, many researchers have incorporated quantum principles into the blockchain to increase its robustness and security. We propose two protocols to build a blockchain that is intrinsically quantum.

In the first, we use multiparty entanglement of highly entangled weighted hypergraph state as a tool to replace the classical ledger and hash functions [1]. The creation of a block remains analogous to that in the classical case. We use the 'weights,' i.e., the phases carried by the hyperedges of the weighted hypergraph states, to encode the classical information in the hypergraph state. We further provide a quantum circuit and implement it on IBM's five-qubit computer with single and two-qubit quantum gates as components. In the second, we show how the generalized Gram-Schmidt method naturally fits into the context of blockchain, resulting in a robust chain structure [2]. The chain is generated as a result of the reliance of orthogonalized states on the sequence of states preceding it. The proposed scheme requires fewer quantum capabilities making it practically realizable even in a small-scale quantum network.

In both the protocols, the peers use only local operations and classical communications over a quantum secure channel to build the chain according to a mutually agreed upon consensus. These protocols can accommodate an infinite number of quantum blocks added by trustless peers.

[1] Banerjee, S., Mukherjee, A., & Panigrahi, P. K. (2020). Quantum blockchain using weighted hypergraph states. Physical Review Research, 2(1), 013322.

[2] Nilesh, K., & Panigrahi, P. K. (2021). Quantum Blockchain based on Dimensional Lifting Generalized Gram-Schmidt Procedure. arXiv preprint arXiv:2110.02763

Squashed entanglement in topological superconductors and topological insulators

Fabrizio Illuminati
University of Salerno

ABSTRACT

NV spins in diamond as a platform for the simulation and control of open quantum systems

Nir Bar-Gill
The Hebrew University of Jerusalem

The study of open quantum systems, quantum thermodynamics and quantum many-body spin physics in realistic solid-state platforms, has been a long-standing goal in quantum and condensed-matter physics.

In this talk I will address these topics through the platform of nitrogen-vacancy (NV) spins in diamond, in the context of purification (or cooling) of a spin bath as a quantum resource and for enhanced metrology.

I will first describe our results on spin-bath cooling using a single optically pumped NV quantum central spin [1]. I will then present a general theoretical framework we developed for Hamiltonian engineering in an interacting spin system [2]. This framework is applied to the coupling of the spin ensemble to a spin bath, including both coherent and dissipative dynamics [3]. Using these tools I will present a scheme for efficient purification of the spin bath, surpassing the current state-of-the-art and providing a path toward applications in quantum technologies, such as enhanced MRI sensing.

1. P. Penshin et. al., in preparation.
2. K. I. O. Ben'Attar, D. Farfurnik and N. Bar-Gill, Phys. Rev. Research 2, 013061 (2020).
3. K. I. O. Ben'Attar et. al., in preparation.

Quantum simulations of interacting systems with broken time-reversal symmetry

Roee Ozeri
Weizmann institute of Science

Many-body systems of quantum interacting particles in which time-reversal symmetry is broken give rise to a variety of rich collective behaviors, and are therefore a major target of research in modern physics. Quantum simulators can potentially be used to explore and understand such systems, which are often beyond the computational reach of classical simulation. Of these, platforms with universal quantum control can experimentally access a wide range of physical properties. However, simultaneously achieving strong programmable interactions, strong time-reversal symmetry breaking, and high fidelity quantum control in a scalable manner is challenging. Here we realized quantum simulations of interacting, time-reversal broken quantum systems in a universal trapped-ion quantum processor. Using a scalable scheme that was recently proposed we implemented time-reversal breaking synthetic gauge fields, shown for the first time in a trapped ion chain, along with unique coupling geometries, potentially extendable to simulation of multi dimensional systems. Our high fidelity single-site resolution in control and measurement, along with highly programmable interactions, allow us to perform full state tomography of a ground state showcasing persistent current, and to observe dynamics of a time-reversal broken system with nontrivial interactions. Our results open a path towards simulation of time-reversal broken many-body systems with a wide range of features and coupling geometries.

Title

William Oliver
MIT

ABSTRACT

Variational Quantum Algorithms using Optimized Pulses on Superconducting Qubits

Steven Frankel
Technion

Variational quantum algorithms (VQAs) are class of hybrid quantum-classical algorithms suitable for NISQ computers. They involve a parameterized quantum circuit ansatz whose parameters are iteratively optimized on a classical computer utilizing a quantum measurement-based cost function. In this talk, we will explore the use of optimized pulses instead of traditional gates in a attempt to improve VQA performance and accuracy.

Supercurrent noise in short ballistic graphene Josephson junctions

Elisabetta Paladino
University of Catania

Short ballistic graphene Josephson junctions sustain superconducting current with a non-sinusoidal current-phase relation up to a critical current threshold. The current-phase relation, arising from proximitized superconductivity, is gate-voltage tunable and exhibits peculiar skewness observed in high quality graphene super-conductors heterostructures with clean interfaces. These properties make graphene Josephson junctions promising sensitive quantum probes of microscopic fluctuations underlying transport in two-dimensions. Understanding material-inherent microscopic noise sources possibly limiting the phase-coherent behavior of GJJ-based quantum circuits represents an essential, still unexplored, prerequisite.

In this presentation we first demonstrate that fluctuations with 1/f power spectrum of the critical current of a short ballistic GJJ directly probe carrier density fluctuations of the graphene channel induced by the presence of charge traps in the nearby substrate, modeled

by a spatially uniform distribution of independent generation–recombination centers. Secondly, we study the effect of a dilute homogeneous spatial distribution of non-magnetic impurities on the equilibrium supercurrent within the Dirac-Bogoliubov-de Gennes approach and modeling impurities by the Anderson model. The potentialities of the supercurrent power spectrum for accurate spectroscopy of the hybridized Andreev bound states-impurities spectrum are highlighted. In the low temperature limit, the supercurrent zero frequency thermal noise directly probes the spectral function at the Fermi energy. Our results suggest a roadmap for the analysis of decoherence sources in the implementation of coherent devices by hybrid nanostructures.

Topological Quantum Integers in Floquet Systems: General Diophantine Equation

Itzhack Dana
Bar Ilan University

ABSTRACT

Short Talk: Symmetry resolved entanglement of 2D symmetry protected topological states

Daniel Azses
Tel Aviv University

Symmetry resolved entanglement has shown to be a useful tool to characterize and experimentally identify symmetry protected topological states in one dimension using quantum computers. We generalize these results to two dimensions by employing an effective one dimensional edge matrix product state formalism. We recover previous results of conformal field theory regarding the spectrum and demonstrate them using different symmetry groups. Additionally, we show how to obtain the symmetry decomposition of the entanglement and recover the expected equipartition properties. Finally, we study the usefulness of the symmetry resolved entanglement by proposing a quantum information teleportation algorithm based on the unique edge entanglement spectrum symmetry decomposition.

Short Talk: Learning Initial Parameters For The Quantum Approximate Optimization Algorithm With Neural Network

Tamuz Danzig
Bar Ilan University

The quantum approximate optimization algorithm (QAOA) is a leading iterative variational quantum algorithm for heuristically solving combinatorial optimization problems. A large portion of the computational effort in QAOA is consumed by the optimization steps which require many executions of the quantum circuit. Finding better initial circuit's parameters, which would reduce the number of required iterations and hence the overall execution time, is therefore a matter of active research. While existing methods for parameters initialization have shown great success, they often offer the same single set of parameters for all problem instances, thereby ignoring deviations that might be utilized. We propose a practical method that uses a simple, fully connected, neural network to find better initialization parameters that are tailored to a new given problem instance. We benchmark state-of-the-art initialization methods for solving the Max-Cut problem of Erdős–Rényi graphs using QAOA, and show that our method consistently converges the fastest and to the best final result.

Day III: Tuesday

Towards interpretable AI for quantum science

Hans Briegel
University of Innsbruck

ABSTRACT

Universal control using the quantum Zeno effect

Shay Hacohen-Gourgy
Technion

The Zeno effect occurs in quantum systems when a very strong measurement is applied, which can alter the dynamics in non-trivial ways. Despite being dissipative, the measurement divides the Hilbert space into subspaces with distinct eigenvalues of the measured observable, and give rise to `Zeno dynamics' within each subspace. The dynamics stay coherent within any degenerate subspaces of the measurement, and surprisingly can transform a trivial (e.g., non-interacting with local control only) quantum system into one with universal control within the Zeno subspace. We will show how the application of such a measurement can turn a single-qubit operation into a two- or multi-qubit entangling gate in a non-interacting system. We demonstrate this gate between two effectively non-interacting transmon qubits. Our Zeno gate works by imparting a geometric phase on the system, conditioned on it lying within a particular non-local subspace. These results demonstrate how universality can be generated not only by non-local coherent interactions as is typically employed in quantum information platforms, but also by dissipative measurements.

Two qubit-efficient variational quantum algorithms

Adi Makmal
Bar Ilan University

The family of variational quantum algorithms (VQA) is a strong candidate for demonstrating quantum advantage on near-term quantum devices. It is often the case in VQAs that the information is encoded such that the logical state of each variable is mapped to the quantum state of a corresponding qubit, i.e. with a one-to-one ratio between the number of variables and the number of qubits (consider e.g. the QAOA or the VQE algorithm).

In this talk I will explore other – more efficient – encodings and present two VQAs, whose qubit-requirements scale merely logarithmically (instead of linearly) with the problem size: **(a) qubit-efficient MaxCut (QEMC) solver** - an efficient VQA for tackling the MaxCut problem with $log\ N$ qubits for graphs with N nodes; and **(b) qubit-efficient selected**

configuration interaction (QE-SCI) algorithm - a variational algorithm for approximating the ground-state of a molecule with $\log D$ qubits for molecular systems that can be described to chemical accuracy with D Slater-determinants.

I will show, via numerical simulations, that our QEMC solver consistently outperforms the best-known, polynomial-time, classical Goemans Williamson (GW) algorithm on graphs with thousands of nodes; In addition, I will show that the proposed QE-SCI algorithm allows the solution of larger molecules with fewer qubits, e.g. H_2 with a single qubit, H_2O with 5 qubits, and C_2H_4 with 12 qubits to chemical accuracy within the sto-3g minimal basis set. I will present noiseless and noisy simulations, alongside with real-hardware calculations, discuss the algorithms' computational resources and outline future directions.

Simulations and cloud-based experiments with IBM Quantum devices

Haggai Landa
IBM Quantum

I will present a brief overview of the IBM Quantum roadmap. A central part in this roadmap is devoted to the cloud-based access offered to IBM's quantum hardware. Together with the devices accessible to the general public and research communities, IBM leads the development of Qiskit, an open-source framework for quantum experiments and simulations. I will present some recently introduced Qiskit tools for the classical simulation of open many-body quantum systems and some recent results, and discuss possibilities for running similar experiments on IBM Quantum devices.

Automatic synthesis of quantum algorithms

Yehuda Naveh
Classiq Technologies

I will describe the benefits and technology for automatically synthesizing quantum algorithms out of high-level functional models. The benefits fall under the categories of the algorithms' usability, maintainability, adaptability to different hardwares, scalability and complexity, and orders of magnitudes better optimized circuits compared to transpiler-style implementation-level optimization. I will demonstrate the power of this approach when applied to superconducting circuits' most apparent Achilles heels - qubit noise and sparse connectivities.

Quantum neurons with dynamic synapses

Daniel Manzano Diosdado
University of Granada

Quantum Neuronal Networks (QNNs) are a new and vivid topic of research. In this talk, we will review some of the most recent models of QNNS and discuss their potential applications. Furthermore, we will explore the emergent behavior of quantum systems with dynamical biologically-inspired qubits interaction. We will discuss a model of two interacting qubits with an activity-dependent dynamic interplay as in classical dynamic synapses that induces the so-called synaptic depression, that is, synapses that present synaptic fatigue after heavy presynaptic stimulation. The role of synaptic depression in learning and information retrieval will also be discussed. Finally, potential applications and experimental realizations will also be discussed.

Erasure qubits: Overcoming amplitude damping errors in superconducting circuits by measurements

Alex Retzker
The Hebrew University of Jerusalem

The amplitude decay time, T_1, has long stood as the major factor limiting fidelity in superconducting-circuit-based quantum computing, prompting a long-time effort in the material science and design of superconducting qubits aimed at increasing T_1 as much as possible. In contrast, the dephasing time, T_{ϕ}, can typically be extended above T_1, e.g. using dynamical decoupling, to the point where it is not limiting the quantum infidelity.

In this work we propose a scheme for overcoming the T_1 limit. We demonstrate numerically that by combining a qubit design that allows for detection of amplitude decay together with an appropriate error-correction scheme, we are able to significantly lower the logical error rate compared with a T_1-limited system. The logical error rate in this case is effectively limited by the dephasing time, T_ϕ, and the quality of quantum coherent control. We propose two appropriate qubit implementations and discuss in detail the procedure for detecting amplitude decay and performing entangling gates, supporting our conclusions with numerical simulations. We further analyze quantum dephasing in each of these implementation and show how one can achieve $T_\phi\gg T_1$ in typical settings.

Realization of quantum neural networks using repeat-until-success circuits in a superconducting quantum processor

Gian Giacomo Guerreschi
Intel

Artificial neural networks are becoming an integral part of digital solutions to complex problems. One of the challenges to realize neural networks on quantum processors comes from the implementation of non-linear activation functions. In this presentation, we describe the experimental realization of quantum neurons with non-linear activation function based on repeat-until-success circuits. Since these circuits are characterized by intermediate measurements, we discuss the necessary control-flow feedback. We also run realistic simulations closely reproducing the experimental data and providing indications about the relevant error sources.

These quantum neurons constitute elementary building blocks that can be arranged in a variety of layouts to carry out machine learning tasks quantum coherently. As an example, we construct a minimal feedforward quantum neural network capable of learning all 2-to-1-bit Boolean functions by optimization of the network parameters within the supervised-learning paradigm. This model is shown to perform non-linear classification and effectively learns from multiple copies of a single training state consisting of the maximal superposition of all inputs.

Transport properties of a tunnel Josephson junction formed by different superconductors under thermal gradient

Claudio Guarcello
University of Salerno

In this work, we delve into the unexpected, and quite intriguing, features showed by the electric transport through a tunnel Josephson junction (JJ) formed by different superconductors residing at different temperatures. In particular, we demonstrate the peculiar behavior of the supercurrent and the quasiparticle current as a function of both the temperatures and the gaps of the superconductors forming the device. We shed light on the role played by the alignment mechanism of the two singularities in the superconducting density of state and its anomalous components. This matching of the singularities can be eventually triggered by different mechanisms determined by temperatures, biasing, or exchange fields.

We first discuss the unusual behavior of the critical current, that is the maximum supercurrent that can flow through the device, which shows abrupt variations, even with the emergence of a counterintuitively non-linear response: in fact, it may even increase by enhancing the temperature of one electrode, instead of monotonically reducing as naively expected. This phenomenon lends itself to a proposal for a single-photon threshold detector operating in the non-dissipative branch. Then, we present the bipolar thermoelectrical effect on the quasiparticle current through a temperature biased JJ with asymmetric gaps, which is generated by the spontaneous breaking of the particle-hole symmetry as determined by a nonlinear thermal gradient applied to the device, when the Josephson current is suppressed.

Finally, we suggest an alternative device configuration taking advantage of the magnetic fluxes through superconducting loops enclosing the electrodes of the JJ, in order to give an effective way to tune the superconducting gaps. We demonstrate the feasibility (and the benefits) of controlling the characteristics of a junction under thermal gradient, by using a more convenient "magnetic knob". The non-trivial experimental advantage of being able to observe this phenomenology in a superconducting system made of only one type of material is also introduced.

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Title

Nissan Maskil
ELTA

ABSTRACT

Title

Gilad Tauber
Reinhold Cohn

ABSTRACT

Day IV: Wednesday

Quantum simulators: from the Fermi Hubbard model to quantum assisted NMR inference

Eugene Demler
ETH Zurich

I will discuss recent progress of the optical lattice emulators of the Fermi Hubbard model. The new feature of these experiments is availability of snapshots of many-body states with single particle resolution. I will review new insights from these experiments on the properties of doped Mott insulators, including demonstration of magnetically mediated pairing. I will also present the idea of using quantum simulators to perform inference of NMR spectra for biological molecules. I will review recent experimental realization of this algorithm on a quantum computer using trapped ions. Prospects for scaling this approach to solving practically relevant problems will be discussed.

Optimal quantum algorithms for oracle problems

Eliahu Cohen
Bar Ilan University

ABSTRACT

Simulating entanglement dynamics on quantum computers

Eran Sela
Tel Aviv University

Quantum computers hold promise for futuristic technologies. We devise new ways to measure quantum entanglement between groups of many qubits, which is an essential resource for any quantum algorithm. In contrast to small numbers of entangled qubits, whose entanglement can be determined by state tomography, verifying the coherence of a quantum computer is a demanding task. We will monitor the many-qubit entanglement dynamics in selected simulations of many-body problems, such as a Floquet phase transition. The examples I will discuss embody concrete realizations of symmetry protected topological phases on quantum computes.

Long-lived Superconducting Quantum Memories

Serge Rosenblum
Weizmann Institute of Science

Quantum memories are an important component of future quantum computers, fulfilling a similar role to storage units in today's computers.

In this talk, I will present our latest results on a quantum memory for superconducting quantum circuits. The relaxation time of our quantum memory exceeds that of state-of-the-art processing qubits by orders of magnitude. I will describe our current efforts in microwave-induced decoupling of the memory from its environment to bring the phase coherence to similar levels.

Outperforming classical simulators at running a quantum optimization algorithm

Maxime Dupont
UC Berkeley & Rigetti Computing

ABSTRACT

Quantum simulation of lattice gauge theories - requirements, challenges and methods

Erez Zohar
The Hebrew University of Jerusalem

Over recent years, the relatively young field of quantum simulation of lattice gauge theories, aiming at implementing simulators of gauge theories with quantum platforms, has gone through a rapid development process. Nowadays, it is not only of interest to the quantum information and technology communities. It is also seen as a valid tool for tackling hard, non-perturbative gauge theory problems by particle and nuclear physicists. Along the theoretical progress, nowadays more and more experiments implementing such simulators are being reported, manifesting beautiful results. In my talk, I will review the essential ingredients and requirements of lattice gauge theories, discuss their meanings, the challenges they pose and how they could be tackled, potentially aiming at the next steps of this field.

Title

Netanel Lindner
Technion

ABSTRACT

Entanglement of macroscopic mechanical objects

Shlomi Kotler
The Hebrew University of Jerusalem

Observing quantum mechanics at the macroscopic scale has captured both the attention of scientists and the imagination of the public for more than a century. Although quantum mechanics presumably applies to objects of all sizes, directly observing entanglement becomes harder as masses increase, requiring measurement and control with a vanishingly small error. Here, using pulsed electromechanics, we deterministically entangle two mechanical drumheads with masses of ~ 70 picograms. Through nearly quantum-limited measurements of the position and momentum quadratures of both drums, we perform quantum state tomography and thereby directly observe entanglement.

Reference: Kotler et. al. Science 372, 622-625 (2021)

Short Talk: Inelastic decay in an integrable model

Amir Burshtein
Tel Aviv University

High probability inelastic decay of a single-photon, a phenomenon rarely observed in nature, has been recently demonstrated in a circuit QED environment [1, 2]. A system comprised of a high-impedance Josephson transmission line galvanically-coupled to a small Josephson junction allows for splitting of microwave photons with order unity probability, and provides a useful tool to probe fundamental phenomena in many-body systems. I will present an ongoing collaboration with the Manucharyan group at the University of Maryland, in which single-photon splitting is utilized in order to probe the Schmid-Bulgadaev quantum phase transition between the superconducting and insulating phases of the small junction, whose observation (or lack thereof) has sparked recent debate [3–6]. The experimental system provides a realization of the boundary sine-Gordon model, which is known to be integrable and possesses an extensive number of conservation laws. These conservation laws restrict the scattering of the integrable excitations of the field theory to be purely elastic, which seems at odds with photon splitting. However, I will show that the nonlinear relation between the integrable excitations and the microwave photons not only allows for inelastic decay of the latter, but also that powerful analytical tools provided by integrability could be used to obtain exact results for the total inelastic decay rate and the spectrum of the

resulting photons. The results compare nicely with measurements by the Manucharyan group.

[1] A. Burshtein, R. Kuzmin, V. E. Manucharyan, and M. Goldstein, Photon-instanton collider implemented by a superconducting circuit, Phys. Rev. Lett. 126, 137701 (2021).

[2] R. Kuzmin, N. Grabon, N. Mehta, A. Burshtein, M. Goldstein, M. Houzet, L. I. Glazman, and V. E. Manucharyan, Inelastic scattering of a photon by a quantum phase slip, Phys. Rev. Lett. 126, 197701 (2021).

[3] A. Murani, N. Bourlet, H. le Sueur, F. Portier, C. Altimiras, D. Esteve, H. Grabert, J. Stockburger, J. Ankerhold, and P. Joyez, Absence of a dissipative quantum phase transition in josephson junctions, Phys. Rev. X 10, 021003 (2020).

[4] P. J. Hakonen and E. B. Sonin, Comment on "absence of a dissipative quantum phase transition in josephson junctions", Phys. Rev. X 11, 018001 (2021).

[5] A. Murani, N. Bourlet, H. le Sueur, F. Portier, C. Altimiras, D. Esteve, H. Grabert, J. Stockburger, J. Ankerhold, and P. Joyez, Reply to "comment on 'absence of a dissipative quantum phase transition in josephson junctions"', Phys. Rev. X 11, 018002 (2021).

[6] K. Masuki, H. Sudo, M. Oshikawa, and Y. Ashida, Absence versus presence of dissipative quantum phase transition in josephson junctions (2021), arXiv:2111.13710 [cond-mat.mes-hall].

Short Talk: Low frequency signal detection via correlated Ramsey measurements

Santiago Oviedo-Casado
The Hebrew University of Jerusalem

Dynamical decoupling protocols often rely on adjusting the time separation between pulses to match the half period of the target signal, limiting their scope to signals whose period is shorter than the T_2 dephasing time of the probe. We show that, in the low frequency regime, rather than struggling to fit dynamical decoupling sequences, it is more advantageous to perform Ramsey measurements carefully controlling the time at which each measurement is initiated. With such time-tagging, information about the phase of the signal is recorded, which crucially allows correlating measurements in post-processing, leading to efficient spectral reconstruction.

Coherent Heatronics

Gershon Kurizki
Weizmann Institute of Science

The flurry of activity in quantum thermodynamics (QTD) has thus far left open the foundational issue: How to bridge the gulf between QTD and quantum coherent dynamics? Quantum coherent dynamics represents unitarily reversible evolution, whereas QTD mostly describes open quantum systems that evolve non-unitarily, and hence irreversibly, as a result of their coupling to heat baths. The non-unitary QTD evolution is incompatible with the nascent quantum technologies of quantum information processing (QIP) and quantum sensing, which are hindered by decoherence and dissipation due to thermal baths. This hindrance reflects the QTD paradigm that open quantum systems are partly controllable, but not the baths—which remain immutable.

The gulf described above can be narrowed down by a radical departure from the existing QTD paradigm: We describe the dynamics of the entire compound ("supersystem"), comprised of quantum systems and heat baths, as tractable coherent processes, nearly free from the hurdles of dissipation. To this end, we aim at engineering the bath that would otherwise prevent the supersystem from exhibiting coherent reversibility and separate it from the slow dynamics caused by their much weaker interactions with additional baths.

Our ultimate goal is to seamlessly bridge the thermodynamic and quantum coherent descriptions by exploring the transition from coherent (unitary) reversibility to irreversibility as the supersystem complexity increases. Our results show that bath engineering can give rise to unprecedented coherent steering of thermodynamic variables (heat, information and work). Analogous bath engineering can yield novel nonlinear regimes of quantum transport that can ensure long-range transfer of energy, information or other variables from heat sources. Finally, coherent steering or storage of thermodynamic variables is demonstrated in novel hybrid circuits composed of spin networks connected to nonlinearly coupled modes. This approach may allow us to overcome the setbacks to quantum technologies caused by thermal bath effects, and enable coherent manipulations of heat.

Short Talk: Measurement induced entanglement phase transitions in correlated 1D spin chains

Monalisa Singh Roy
Bar Ilan University

Entanglement phase transitions have attracted immense attention in recent years especially in the context of monitored quantum circuits. In such systems the dynamics due to unitary evolution compete with the localization induced by measurements. The phase transition of quantum systems from a phase where its entanglement entropy exhibits volume law for weak monitoring, to a quantum Zeno like phase where the entanglement entropy obeys area law is well known in many models with unitary dynamics. Some recent proposals have identified a critical phase with a logarithmic scaling of entanglement in non-Hermitian models. We explore such a critical transition in a monitored quantum spin chain model and identify the entanglement transitions in the system under both unitary and non-unitary evolutions.

Short Talk: Approximate encoding of quantum states using shallow circuits

Matan Ben Dov
Bar Ilan University

A common requirement of quantum simulations and algorithms is the preparation of complex states through sequences of 2-qubit gates. For a generic quantum state, the number of gates grows exponentially with the number of qubits, thereby setting a strict barrier for exact state preparation on near-term quantum devices. In this talk, I will present an efficient method for creating an approximate encoding of a target state using a limited number of gates [1]. In the first part of the talk, I will focus on a classical implementation of the algorithm and demonstrate its performance by comparing the optimal and suboptimal circuits on real devices. Then, in the second part of the talk, I will consider a direct implementation of the proposed algorithm on a quantum computer and show how to overcome inherent barren plateaus by employing a local cost function rather than a global one. I will further examine how many shots are required to reach optimization convergence and show that the number of shots scales merely polynomially with the number of qubits.

[1] arXiv: https://arxiv.org/pdf/2207.00028.pdf

The importance of N in NISQ

John Martinis
University of California, Santa Barbara

Day V: Thursday

Boosting noise mitigation performance in IBM processors

Raam Uzdin
The Hebrew University of Jerusalem

Quantum error mitigation (QEM) is an approach for improving the accuracy of computations without hardware overhead as in quantum error correction codes. In QEM, the noise if first mapped by taking some extra measurements, and then the noise is mitigated in post processing. Unfortunately, some of these methods are heuristic without a proper theory, some assume over restrictive noise model and others are non-scalable. We present a new approach to QEM with supporting time-dependent derivation. Interestingly, the weak noise limit of our method converges to a variant of the zero noise extrapolation method called unitary folding. However, our method significantly outperform unitary folding when the noise is strong. Moreover our method shows why the standard practice of unitary folding leads to incorrect result and why pulse level control is mandatory. Mitigation results in a thirty cnot depth circuit in IBM will be presented.

Optimal inertial protocols for quantum computation

Adi Pick
The Hebrew University of Jerusalem

We explore a new class of rapid and robust protocols for quantum information processing. These protocols are similar in spirit to adiabatic population transfer (e.g., STIRAP), but with the adiabatic condition relaxed. Following a recent proposal by Dann and Kosloff [1], we transform the Hilbert space into an “inertial” frame of reference, where we find protocols that are adiabatic in that frame but rapid in the lab frame. To demonstrate the full advantage of our method, we use quantum optimal control. While brute force optimization often yields solutions that are hard to realize in practice, we develop an algorithm that finds feasible optimal solutions. Specifically, we impose state-dependent constraints [2], carefully chosen to force the system to adhere to specific subspaces of the Hilbert space during its evolution. As an application of our method, we implement a proposal by Molmer et al. [3] and perform numerical simulations of rapid and robust geometric single-qubit gates. The same principles can be used, more generally, to improve a large set of protocols, including adiabatic quantum computation schemes and the design of adiabatic optical couplers.

[1] Dann, R. and Kosloff, R., 2021. Inertial theorem: Overcoming the quantum adiabatic limit. Physical Review Research, 3(1), p.013064

[2] Palao, J.P., Kosloff, R. and Koch, C.P., 2008. Protecting coherence in optimal control theory: State-dependent constraint approach. Physical Review A, 77(6), p.063412.

[3] Møller, D., Madsen, L.B. and Mølmer, K., 2007. Geometric phase gates based on stimulated Raman adiabatic passage in tripod systems. Physical Review A, 75(6), p.062302.

Title

Nadav Katz
The Hebrew University of Jerusalem

ABSTRACT

Understanding the interplay of particle conservation and long-range coherence with quantum computers

Emanuele Dalla Torre
Bar Ilan University

Lasers and Bose-Einstein condensates (BECs) exhibit macroscopic quantum coherence in seemingly unrelated ways. Lasers possess a well-defined global phase and are characterized by large fluctuations in the number of photons. In BECs of atoms, instead, the number of particles is conserved and the global phase is undefined. Here, we use gate-based quantum circuits to create a unified framework that connects lasers and BEC states. Our approach relies on a scalable circuit that measures the total number of particles without destroying long-range coherence. We introduce two complementary probes of global and relative phase coherence, and study how they are affected by measurements of the particle number. We find that particle conservation {\it enhances} long-range phase coherence, highlighting a mechanism used by superfluids and superconductors to gain phase stiffness.

Poster Session

Symmetric inseparability and number entanglement in charge conserving mixed states

Zhanyu Ma
Tel Aviv University

We explore sufficient conditions for inseparability in mixed states with a globally conserved charge, such as a particle number. We argue that even separable states may contain entanglement in fixed charge sectors, as long as the state can not be separated into charge conserving components. As a witness of symmetric inseparability we study the number entanglement (NE), \Delta S_m, defined as the entropy change due to a subsystem's charge measurement. Whenever \Delta S_m > 0, there exist inseparable charge sectors, having finite (logarithmic) negativity, even when the full state is either separable or has vanishing negativity. We demonstrate that the NE is not only a witness of symmetric inseparability, but also an entanglement monotone. Finally, we study the scaling of \Delta S_m in thermal 1D systems combining high temperature expansion and conformal field theory.

Inertial protocols for quantum computation

Daniel Turyansky
The Hebrew University of Jerusalem

We explore a new class of rapid and robust protocols for quantum information processing. These protocols are similar in spirit to adiabatic population transfer methods (e.g., STIRAP), but with the adiabatic condition relaxed. Following a recent proposal by Dann and Kosloff [1], we move to a new "inertial" frame of reference, where we find protocols that are adiabatic in that frame but rapid in the lab frame. We use optimal control to demonstrate the superiority of our method. Specifically, we generalize Krotov's method to include state-dependent constraints [2], thereby forcing our system to adhere to inertial-frame constants of motion. As an application of our method, we implement a proposal by Molmer et al. [3] and perform numerical simulations of rapid and robust geometric single-qubit gates.

[1] Dann, R. and Kosloff, R., 2021. Inertial theorem: Overcoming the quantum adiabatic limit. Physical Review Research, 3(1), p.013064

[2] Palao, J.P., Kosloff, R. and Koch, C.P., 2008. Protecting coherence in optimal control theory: State-dependent constraint approach. Physical Review A, 77(6), p.063412.

[3] Møller, D., Madsen, L.B. and Mølmer, K., 2007. Geometric phase gates based on stimulated Raman adiabatic passage in tripod systems. Physical Review A, 75(6), p.062302.

LightSolver – A New Quantum-inspired Computing Paradigm

LightSolver group

Ruti Ben Shlomi, Harel Primack and Idan Meirzada

The increasing complexity of required computational tasks alongside the inherent limitations in conventional computing calls for disruptive innovation. LightSolver devised a new quantum-inspired computing paradigm, which utilizes an all-optical platform for solving hard optimization problems. In this poster, we start by introducing LightSolver's all-optical solver, and present the performance of its digital simulator against the 3-Regular 3-XORSAT challenge, which aims to map the best available state-of-the-art classical and quantum solvers [1]. We show that our simulator is the first to scale sub-exponentially (for the problems size tested), outperforming both classical and quantum platforms by several orders-of-magnitude, and extending the maximal problem size from a few hundred variables to more than 16,000 variables. Next, we utilize our expertise to address a real-world problem. Sparse coding is a fundamental estimation problem, in which the goal is to accurately recover an unknown sparse vector from a few noisy linear measurements of it. We formulate the most general sparse coding problem as a quadratic unconstrained binary optimization (QUBO) problem (which is currently supported by the simulator) in a unique and efficient form, and demonstrate its advantage over baseline methods using the optical solver's simulator.

Title

Ofir Milul

Weizmann Institute of Science

ABSTRACT

Title

Nitzan Kahn

Weizmann Institute of Science

ABSTRACT

Title

Sergey Hazanov

Weizmann Institute of Science

ABSTRACT

Application of KIK protocol for error mitigation in IBM Quantum devices

Jader Pereira dos Santos
The Hebrew University of Jerusalem

We applied the KIK protocol for error mitigation in different IBM devices. We also show how to implement the backward evolution using the real-time pulse-level instructions.

Nonvolatile voltage-tunable ferroelectric-superconducting quantum interference memory devices

Maria Badarne
Technion

ABSTRACT

Title

Sergei Masis
Technion

ABSTRACT

Simulating long-range hopping with periodically driven superconducting qubits

Mor M. Roses
Bar Ilan University

Quantum computers are a leading platform for the simulation of many-body physics. This task has been recently facilitated by the possibility to program directly the time-dependent pulses sent to the computer. Here, we use this feature to simulate quantum lattice models with long-range hopping. Our approach is based on an exact mapping between periodically driven quantum systems and one-dimensional lattices in the synthetic Floquet direction. By engineering a periodic drive with a power-law spectrum, we simulate a lattice with long-range hopping, whose decay exponent is freely tunable. We propose and realize experimentally two protocols to probe the long tails of the Floquet eigenfunctions and identify a scaling transition between long-range and short-range couplings. Our paper offers a useful benchmark of pulse engineering and opens the route towards quantum simulations of rich nonequilibrium effects.

Flux qubits on diamond

Itamar Holzman
Bar Ilan University

ABSTRACT

Title

Noga Entin
Bar Ilan University

ABSTRACT

Title

Rotem Malkinson
The Hebrew University of Jerusalem

ABSTRACT