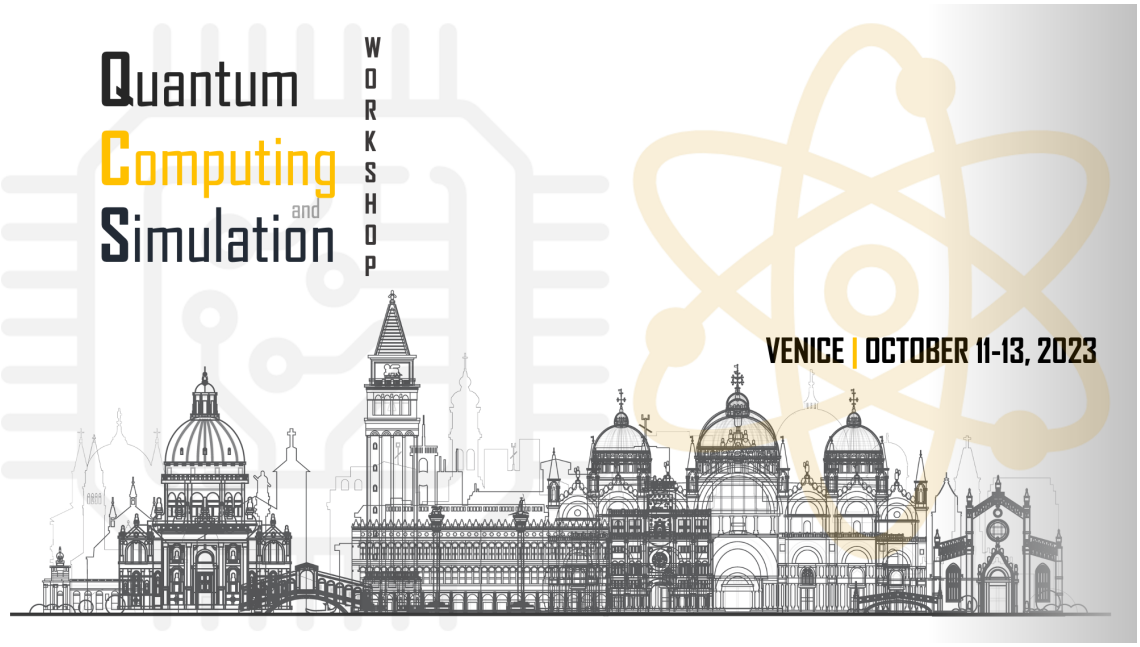
QUANTUM COMPUTING AND SIMULATION WORKSHOP

BOOK OF ABSTRACT



List of talks

INFN activities and contributions within the Quantum Computing Spoke of the ICSC National Research Centre for High Performance Computing, Big Data and Quantum Computing

Valter Bonvicini - INFN Ferrara

The ICSC Center conducts R& D, nationally and internationally, for innovation in high-performance computing, simulations, and big data analytics. It is organized in a Hub and Spoke Model. Within Spoke 10 (Quantum Computing) INFN is actively involved in WP1 (Software) and WP3 (Firmware and Hardware Platforms). Concerning the software domain, we present studies on the entropy of the circuits utilised in quantum machine learning, and its influence on performance. We summarise the status of studies on charged particle tracking by utilising quantum graph neural networks, and on a simulation with quantum generative adversarial networks. For WP3, we present updates on the development and test of superconducting quantum-circuits based on transmon qubits, and on the development of firmware and software tools for qubit control based on RFSoC FPGA boards.

Quantum firmware: optimal control for quantum simulators

Tommaso Calarco - Forschungszentrum Jülich

Quantum optimal control has been shown to improve the performance of quantum technology devices up to their limits in terms e.g. of system size and speed of operation. I will review our recent results with a variety of quantum technology platforms, focusing in particular on ultracold atoms, and introduce our newly developed software for automatic calibration of quantum operations - the fundamental building block of next-generation quantum firmware.

Quantum Magic: from entanglement spectrum to Pauli sampling and Neural Network

Mario Collura - SISSA Trieste

In this seminar, we embark on a journey through the enchanting realm of quantum magic, which serves as a potent resource in quantum computing. We unravel the intricacies of non-stabilizerness and its intimate connection with entanglement spectrum flatness. Discover an innovative approach to quantify non-stabilizerness using Stabilizer Rényi Entropies, with efficient sampling techniques for Matrix Product States. We delve into the nonlocality of magic through statistical exploration of Pauli strings via Markov chains, presenting a versatile method applicable to diverse quantum systems. Witness the transformative power of magic in one-dimensional quantum systems, revealing connections to conformal quantum criticality, and the critical scaling behavior observed in two-dimensional lattice gauge theories. Additionally, we unveil a practical path based on Convolutional Neural Network, to classify quantum states on the basis of their quantum resource content, relying solely on measurements of Pauli observables.

Extending the scope of quantum computing for chemical investigations

Stefano Corni - University of Padova

Chemistry has been identified early as a promising field to benefit from quantum computing. In particular, the accurate determination of electronic state energies and wavefunctions of molecules is a primary target, that attracted remarkable research efforts. On top of that, many more quantities and properties are needed to provide useful information for chemists, ranging from molecular structures, to spectroscopy, dynamics and interactions with the environment surrounding the molecules. In this talk I will present some of the contributions of our group along these directions, i.e., developing quantum or hybrid algorithms for the calculations of chemically relevant quantities and properties.

Quantum Computing for Information Retrieval Tasks

Paolo Cremonesi - Politecnico of Milan

Information Retrieval (IR) and Recommender Systems (RS) play a fundamental role in providing access to and retrieving relevant resources to meet our information needs. To achieve this, they confront ever-increasing volumes of data and increasingly rely on computationally demanding approaches. In this challenging context, Quantum Computing can be leveraged to enhance the performance of IR and RS methods. The aim of this presentation is to explore whether and how Quantum Computing can improve the efficiency and effectiveness of IR and RS systems

On some of UNIBO's Research Contributions to Spoke 10

Ugo Dal Lago/Elisa Ercolessi - University of Bologna

Quantum computing: advances in hardware and software components

Carlo Danieli - ISC-CNR

In recent years, intense research activity has been devoted to the long-term goal of realizing scalable, universal quantum computers. Open issues toward this goal range from developing efficient quantum algorithms to engineering robust and reliable quantum hardware components suppressing the impact of the environmental noise. The CN HPC Spoke 10 main research lines are: (i) the development of applications employing quantum computers to perform otherwise unsolvable problems - a crucial step toward the achievement of quantum advantage; (ii) the realization of hardware and software tools that facilitate the programming of quantum computers and their interoperability with traditional computers; and (iii) the development of large and scalable quantum processors. In this talk, I will briefly recap the progresses of the Spoke in the development of advanced quantum applications with quantum photonics and atomic platforms and discuss how the paradigm of non-Abelian Thouless pumping can be used to design discrete-time quantum walks paving the way to the implementation of holonomic gates and novel quantum algorithms.

Activities on Quantum Computing at the University of Pisa

Massimo D'Elia - University of Pisa

We report on recent activities on Quantum Computing performed at the University of Pisa within the ICSC National Center, with a focus on progress regarding the development and benchmark of quantum algorithms.

Real-time simulation of the lattice Schwinger model on NISQ hardware

Paolo Facchi - University of Bari/INFN Bari

We implement an algorithm to simulate the real-time dynamics of the (1+1)-d lattice Schwinger model with discrete gauge group Z_n on digital quantum hardware. The algorithm is run on a superconducting-qubit platform and the results are compared with noise models to characterize the performance in the absence of error mitigation. Furthermore, we propose an implementation on a Rydberg-atom platform and investigate the limitations in digital simulation imposed by noise affecting the single- and two-qubit gates of the two architectures.

Selected topics from the UniCT node

Giuseppe Falci - University of Catania

The Unict node contributes to the ICSC National Center in three areas, namely: (a) quantum-improved versions of classical algorithms; (b) software for simulation of specific hardware implementations of quantum computers; (c) cryogenic CMOS electronics. Advances in these areas will be reported.

Compact Quantum Circuits for Quantum Chemistry

Leonardo Guidoni - University of L'Aquila

Solving the electronic structure of correlated lattice models and quantum chemistry molecular systems will probably be one of the firsts problems in which quantum computers might show advantage over classical computers. In the present contribution, we report a proposal to build an empirical ansatz for the ground state of the molecular Hamiltonian inspired by the analysis of quantum information based on approximate quantum chemistry calculations. Using the optimization procedure as described by the Wavefunction-Adapted Hamiltonian Through Orbital Rotation (WAHTOR) method, we have previously demonstrated that we can build short depth circuits for highly correlated empirical ansatz for quantum computing. For the investigated representative molecules, we have shown that natural orbitals are the orbitals providing lowest variational energies for an empirical ansatz of fixed topology. Interestingly, the resulting quantum mutual information matrix built on such orbitals is also maximally compact, providing a clear picture of how such orbital choice can provide the optimal basis to develop compact wavefunctions to describe electron correlation. In such way the correlation is encoded in a smaller number of qubit pairs contributing to the quantum mutual information matrix. Based on these results, we designed new Quantum Information-Driven Ansatz (QIDA) with topologies inspired by the natural orbitals and mutual information of approximate quantum chemistry calculations (such as MP2). The resulting mutual information matrix is utilized to determine the correlation between qubits, enabling the development of a new design of entangling blocks for the circuit.

Computing Excited States for the Schwinger Model with the Concurrent Variational Quantum Eigensolver

Yibin Guo - CQTA/DESY

The Schwinger model describes the QED in two-dimensional space-time. In this talk, I will present some results on the excited states of the lattice Schwinger model with the concurrent variational quantum eigensolver (cVQE). First, I will introduce elements of cVQE from the density matrix. Then, I will report results on the spectrum of the lattice Schwinger model, including nonvanishing background field, using a staggered Hamiltonian formulation. Finally, a novel method for extracting the additive mass renormalisation of the model from the energy gap will be discussed.

Research activities at Trento - Quantum solutions for quantum field theories and beyond

Philipp Hauke - University of Trento

The solution of quantum field theories are one of the main drivers of scientific high-performance computing. Conventional approaches, however, are plagued by seemingly insurmountable challenges. Quantum computing and simulation may provide a feasible pathway for major progress, with the potential for key breakthroughs across many scientific disciplines, from high-energy physics, cosmology, and nuclear physics to condensed matter, material design, and even biophysics. In this talk, I will give a hint at the Trento activities in this sector. To stimulate additional interactions, I will also provide a very brief overview of other research activities at the Trento quantum center Q@TN, which encompass–among others–photonic and atomic devices, quantum optimization, as well as quantum approaches to computational biophyics.

Probing anomalous transport of (integrable) spin chains

Zala Lenarčič - Jožef Stefan Institute

Integrable systems typically exhibit non-generic transport properties. The spin 1/2 Heisenberg model is particularly rich, with ballistic transport of energy and different regimes of spin transport, including ballistic, diffusive, and super-diffusive ones. I will use tensor network techniques and coupling to baths to discuss the fate of the diffusive and super-diffusive regimes under different types of Hamiltonian perturbations and show that symmetry of perturbations can play an important role. For example, perturbations that respect the SU(2) symmetry of the isotropic Heisenberg model can cause anomalous transport behaviour even away from exact integrability, for all magnetization sectors. At the end, I will touch also the transport nature of spin systems in Stark field and discuss the reasons for observed sudiffusive transport in that case.

Quantum protocols for image compression and channel reconstruction

Chiara Macchiavello - University of Pavia

We introduce a quantum version of the classical JPEG algorithm, where a digital image is compressed by filtering its high spatial-frequency component. Similarly, the proposed quantum protocol uses the quantum Fourier transform to discard the high-frequency qubits of an image, downsampling it to a lower resolution. This allows to capture, compress and send images even with limited quantum resources for storage and communication. We show under which conditions this protocol is advantageous with respect to its classical counterpart. Moreover, we show recent results about techniques for Pauli transfer matrix direct reconstruction for the characterization of multi-qubit quantum channels and further results achieved in Pavia.

Contributions to the development of photonic and superconducting quantum processors at the University of Milano-Bicocca

Angelo Nuciotti - University of Milan Bicocca

We present an update on UNIMIB's ongoing efforts to realize quantum processor prototypes based on the photonic and superconducting platforms. On the photonic front, UNIMIB is developing deterministic single emitters. These emitters are based on Quantum Dots, engineered using nanostructured heterostructures composed of GaAs/AlGaAs semiconductors and realized by means of droplet epitaxy. We report here the results of first QD on GaAs(111)A substrates with single photon emission in the 780-795 nm wavelength window and linewidth below 0.08 meV. For the superconducting quantum processor UNIMIB is collaborating with INFN and CNR-IFN to develop a prototype processor featuring coupled transmon qubits, traveling wave superconducting paramplifiers, and a control and read-out system based on a RFSoC board. Here we report the results of the device design and simulation and we present the first transmon samples fabricated at NIST (Boulder, USA) as tests and references. We also report the testing carried out at TII (Abu Dhabi) using commercial RFSoC FPGA boards to control and readout up to three flux tunable qubits.

Quantum Computing at CINECA: Integrating a Quantum Accelerator into an HPC Environment

Daniele Ottaviani - CINECA

The rapid advancements in quantum computing technology have ushered in an era of unprecedented computational potential. CINECA, in collaboration with five other leading European countries, has been designated as a Hosting Entity for an EuroHPC Joint Undertaking quantum computer. This talk elucidates the role played by CINECA in the integration of quantum accelerators within High Performance Computing (HPC) environments, contributing to mark a crucial milestone towards achieving computing power beyond the exascale realm. The presentation will delve into the intricacies of amalgamating quantum computational paradigms with traditional HPC architectures, addressing the critical challenges and opportunities that arise in this process. Key considerations encompassing hardware compatibility, resource allocation, and workflow optimization will be discussed, shedding light on the methodologies employed to harness the synergistic potential of quantum-accelerated computing within a well-established HPC ecosystem. Furthermore, the talk will provide insights into the collaborative efforts and interdisciplinary expertise harnessed by CINECA's scientific community. The integration of quantum accelerators into the HPC infrastructure necessitates a convergence of quantum algorithm development, quantum hardware engineering, and classical computing expertise, thereby fostering a holistic approach towards achieving the "quantum advantage".

Introduction to Quantum-Computing and Simulation based on neutral atoms

Tilman Pfau - Stuttgart University

We will introduce the platform of ultracold atoms in optical traps for the realization of large arrays of qbits. Importantly we discuss the physics of coherent Rydberg excitation allows for strong switchable and state dependent interaction. We will describe state of the art of this young but rapidly evolving platform for Quantum-Computing and Simulation.

Multi-qubit gates for quantum computing with neutral atoms

Guido Pupillo - Strasburg University

Neutral atoms have emerged as a competitive platform for digital quantum simulations and computing. In this talk, we discuss recent results on the design and experimental realization of time-optimal and robust multi-qubit gates for neutral atoms. We present a family of high-fidelity Rydberg blockade gates that are robust against common experimental imperfections and demonstrate that they outperform existing gates for moderate or large imperfections. In the context of logical qubits, these gate protocols may significantly reduce the laser stability and atomic temperature requirements to achieve fault-tolerant quantum computing for certain types of neutral atoms qubits. We discuss alternative schemes for achieving fast deterministic non-local multi-qubit quantum gates on qubits coupled to a common driven cavity mode and suggest possible applications for quantum simulations and error correction.

Two-way communication between high-energy physics and quantum matter

Enrique Rico Ortega - University of the Basque Country (UPV/EHU) & Ikerbasque

We will present the results of an interdisciplinary collaboration between groups working in high-energy physics and quantum matter during these last years. First, we will show how it is possible to do the "Quantum Simulation of Light-Front Parton Correlators" [Phys. Rev. D 104, 014512 (2021)] where quantum technologies can help to calculate ab initio correlators that characterize non-perturbative aspects of QCD. Second, we will show how enters the "Role of anomalous symmetry in $0-\pi$ qubits" [Phys. Rev. B 105, L201104 (2022)] and how the notion of the anomaly explains the robustness of this qubit to decoherence. To conclude, we will present an efficient and deterministic protocol to prepare the ground state of non-trivial lattice gauge models even in the presence of noise: "Noise-aware variational eigensolvers: a dissipative route for lattice gauge theories".

Quantum Computation and Simulation with Qudits

Martin Ringbauer - Innsbruck University

Today's quantum computers and simulators are almost exclusively built for binary information processing. Yet, the underlying quantum information carriers are almost always inherently multilevel systems. Similarly, many quantum simulation applications are naturally formulated in terms of high-dimensional Hilbert spaces. I will discuss how we can achieve universal quantum information processing with trapped-ion qudits, and how we can use these systems not only to natively simulate high-dimensional problems, but also to drastically improve the experimental overheads in the characterization of quantum states and the training of variational circuits.

Quantum computing with trapped ions

Ferdinand Schmidt-Kaler - Mainz University

Quantum technologies allow for fully novel schemes of hybrid computing. We employ modern segmented ion traps. I will sketch architectures, the required trap technologies and fabrication methods, control electronics for quantum register reconfigurations, and recent improvements of qubit coherence and gate performance. Currently, gate fidelities of 99.995% (single bit) and 99.8% (two bit) are reached. We are implementing a reconfigurable qubit register and have realized multi-qubit entanglement and fault-tolerant syndrome readout in view for topological quantum error correction and realize user access to quantum computing. The setup allows for mid-circuit measurements and real-time control of the algorithm. Currently, we are investigating various QC applications, including variational quantum eigensolver approaches for chemistry or high energy relevant models, and measurement-based algorithms. While the current IQuAn architecture joins shuttling and addressing of 50 to 100 qubits, for scaling beyond we envision trapping devices will feature X-junctions and enable shuttling in 2D and integrated optics for qubit access. Challenges are addressed with novel trap devices that we fabricate in our clean room facility. Furthermore, the start-up neQxt is providing quantum computing remote acces and quantum computing hardware for commercial users from industry, technology and business.

Hybrid Photonics Platform for Quantum Computing

Fabio Sciarrino - University of Rome La Sapienza

The development of optical quantum technologies allows for quantum-enhanced metrology, secure quantum communication, and quantum computing and simulation in highly increased dimensions. Maturing quantum photonics requires efficient generation and detection of single photons, as well as their scalable manipulation. We merge highly efficient multi-photon sources and integrated waveguide components. In particular, we interface these scalable platforms, demonstrating high-rate multi-photon interference with a quantum dot based multi-photon source and a reconfigurable photonic chip on glass. We will then review applications of this platform to quantum computing and quantum information processing.

Tensor Network applications for quantum computing

Ilaria Siloi - University of Padova

Tensor networks (TNs) have emerged as a powerful framework for the efficient representation of quantum many-body wave functions. TNs have been successfully applied to diverse domain, including quantum many-body systems, lattice gauge theories, and machine learning. Moreover, TNs are currently pivotal in advancing quantum technologies, serving as core components of classical emulators. Here, we introduce our emulators tailored for digital quantum computing and quantum simulators, with a specific focus on the relevant setting of the Hubbard model on a two-dimensional square lattice. Additionally, we harness TN algorithms to tackle complex optimization problems of industrial significance, such as the optimization of satellite scheduling for mission planning in the domain of Earth observation.

Quantum computing for classical fluids: where do we stand?

Sauro Succi - Istituto Italiano di Tecnologia

We present a pedagogical introduction to the current state of quantum computing algorithms for the simulation of classical fluids. Different strategies, along with their potential merits and liabilities, are discussed and commented on.

Quantum Computing activities at INAF

Roberto Scaramella - INAF

I will give an overview of the fledgling INAF interests in Quantum Computing and present a few use cases.

The superconducting platform for quantum computation in Napoli: project advances, quantum circuits and experiments

Francesco Tafuri - University of Naples Federico II

A brief overview of the activities at the University of Napoli Federico II according to the research plan of Spoke 10 will be provided. Experiments and main achievements will be presented along with the status of the new facility under construction of a superconducting quantum computer with a number of qubits larger than 30.

Activities have been aimed at the characterization of a 5-qubit superconducting quantum processor (sQPU). The device includes a central qubit connected in a "star-like" fashion with other four flux-tunable qubits by means of high-frequency (~ 30 GHz) bus resonators. The sample design features specific qubit frequencies layout, in line with surface code superconducting QPUs. We have performed a full characterization through Ramsey and Spin-Echo protocols and spectroscopy measurements to prepare iSWAP and CZ Gates and we have realized the Bell state. We have finally performed a hybrid quantum-classical algorithm for readout correction on two qubits for the first time in Italy. We are developing the new type prototype of superconducting transmon based on tunnel-ferromagnetic Josephson junctions (ferrotransmon). We will work on scaling the dimension of Al-based

ferromagnetic Josephson junctions to the appropriate window of parameters and test other ferromagnets as barriers, in view of the final 5 qubit quantum processor. We have made further progress on a new read-out device we have invented for the detection of weak coherent tones (the Josephson Digital Phase Detector (JDPD)) capable of discriminating between two phase values of a coherent input tone at GHz frequency. Experiments with JDPD integrated with standard transmon qubits are actually in progress. We are also characterizing near-quantum-limited Josephson-based parametric amplifiers to integrate them into the conventional amplification chain for readout of superconducting qubits for the achievement of high-fidelity multiplexed single-shot readout of superconducting QPUs.

List of posters

Gauge-theoretic origin of Rydberg quantum spin liquids

Riccardo Andreoni - SISSA Trieste

Recent atomic physics experiments and numerical works have reported complementary signatures of the emergence of a topological quantum spin liquid in models with blockade interactions. However, the specific mechanism stabilizing such a phase remains unclear. Here, we introduce an exact relation between an Ising-Higgs lattice gauge theory on the kagome lattice and blockaded models on Ruby lattices. This relation elucidates the origin of previously observed topological spin liquids by directly linking the latter to a deconfined phase of a solvable gauge theory. By means of exact diagonalization and unbiased quantum Monte Carlo simulations, we show that the deconfined phases extend in a broad region of the parameter space; these states are characterized by a large ground state overlap with resonating valence bond wavefunctions. These blockaded models include both creation/annihilation and hopping dynamics, and can be experimentally realized with Rydberg-dressed atoms, offering novel and controllable platforms for the engineering and characterization of spin liquid states.

First-order superradiant phase transition in magnetic cavities: A two-leg ladder model

Zeno Bacciconi - SISSA Trieste

Recently, the existence of Dicke-like equilibrium superradiant phase transitions in cavity QED many-body system has been put into question - resulting in no-go theorems on spontaneous photon condensation. Specifically, the no-go theorems tells us that the superradiant phase transition is prohibited as long as a single-mode purely electrical vector potential is considered, with the transition being analogous to a magnetostatic instability. In this work we consider a minimal setting beyond 1D - i.e., a two-leg ladder - where the orbital motion of spinless fermions is coupled through Peierls substitution to a non-uniform cavity mode which generates a fluctuating magnetic field. Thanks to the quasi-one dimensional geometry we are able to scrutinize the accuracy of (mean field) cavity-matter decoupling against large scale density-matrix renormalization group simulations and study light-matter entanglement properties as well as the exact cavity state. Our results show that ladder geometries can indeed photon condensation and in particular they serve as a first simple example of first-order photon condensation in a gauge-invariant scenario; highlighting how, in the quest for new photon condensed phases, looking for instabilities of the normal phase might be limiting.

Scalable digital quantum simulation of lattice fermion theories with local encoding

Marco Ballarin/Giovanni Cataldi - University of Padova

We demonstrate the feasibility of a platform-neutral, general strategy to perform quantum simulations of fermionic lattice field theories under open boundary conditions. The digital quantum simulator requires solely one- and two-qubit gates and is scalable since integrating each Hamiltonian term requires a finite (non-scaling) cost. Our strategy relies on auxiliary $\mathbb{Z}_2$ lattice gauge fields which make the fermion theory genuinely local without changing its dynamics. By numerically emulating the quantum simulator real-time dynamics, we observe spin-charge separation phenomena for a spin-$\frac{1}{2}$ Hubbard. We also show that such local fermion encoding is also useful in tensor network numerical simulations.

Development and validation of a superconducting qubit control and readout system based on the RFSoC board

Agata Barsotti - University of Pisa

We propose a system for the control and readout of superconducting qubits, based on the recently released board Xilinx RFSoC 4×2. This board integrates high-speed DACs, ADCs, programmable FPGA logic, and a standard microprocessor, all on a single platform. Our system features also purposely designed up and down conversion chains, needed because the RFSoC 4x2 board has a maximum output frequency of 4 GHz. The software and FPGA firmware, required for the generation and acquisition of Gaussian pulses, were derived by suitably adapting the files provided in the documentation of QICK, an open-source platform developed by a research team at FermiLab, with which we currently have a collaboration. The RFSoC board simplifies the overall architecture since it allows the direct synthesis of I/Q modulated Gaussian pulses and their demodulation. For the up and down-conversion chain we have developed a synthesized variable frequency local oscillator. Since its output signal exhibited an output power not constant in the frequency range of interest, it has been necessary to implement an amplifier stage with automatic gain control. To achieve high spectral purity, we integrated a YIG filter following the up-conversion chain. We have then completed a series of tests to characterize the system performance, paying particular attention to phase noise reduction. Maintaining a low level of phase noise values is crucial to achieve good fidelity.

Parameterized quantum circuits for anomaly detection and generative tasks

Andrea Cacioppo - University of Rome La Sapienza

We investigate the possibility of applying parameterized quantum circuits, in particular, quantum autoencoders, for different machine learning tasks. The first application is for anomaly detection in handwritten digits as well as more complex structures like anomalous patterns in particle detectors. This algorithm has been trained on a classical computer and tested with simulations and on real quantum hardware. Tests on NISQ devices have been performed with IBM quantum computers. The second application is a preliminary study about the possibility of applying parameterized quantum circuits for generative tasks. In this study, the quantum circuit has been used in the denoising steps of a quantum diffusion model.

Singlet fission and triplet fusion in extended media

Francesco Campaioli - University of Padova

Singlet fission is a process in which a photo-excited electronic state with spin $s = 0$ (singlet exciton) splits into two excited electronic states with spin $s = 1$ (triplet excitons). This multi-exciton generation process occurs in organic semiconductors (such as polyacenes) and is a promising approach to improve the efficiency of photovoltaics beyond the limits of standard single-junction technology. Together with its "counterpart" triplet fusion (TF), singlet fission also finds application in optoelectronics, cancer therapy and volumetric 3D printing. These electronic processes are fairly well understood for gas and liquid phases, molecular dimers, and dilute crystals. However, for applications like solar cells, we must understand how they behave in extended solids, such as molecular crystals and amorphous polymers. A major obstacle is posed by the fact that exciton dynamics in these materials is notoriously hard to model - and thus to optimise -, even for single-particle transport problems, due to the interplay between excitons and molecular vibrations (phonons). Here we tackle this problem with two approaches. First, we show that weak singlet-triplet couplings are sufficient for using perturbative methods, even in the presence of strong singlet-singlet and triplet-triplet interactions. Then we demonstrate that TNMs are a powerful method for tackling non-perturbative, genuinely many-body scenarios. With these tools, we can optimize SF and TF for specific applications: For example, in organic solar cells, we can seek to promote multi-exciton generation and prevent the back reaction.

Approaching dark matter simulations with quantum computers

Luca Cappelli - University of Trieste

Cosmological simulations describing the evolution of density perturbations of a self-gravitating collisionless Dark Matter (DM) fluid in an expanding background, provide a powerful tool to follow the formation of cosmic structures over wide dynamic ranges. The most widely adopted approach, based on the N-body discretization of the collisionless Vlasov-Poisson (VP) equations, is hampered by an unfavourable scaling when simulating the wide range of scales needed to cover at the same time the formation of single galaxies and of the largest cosmic structures. On the other hand, the dynamics described by the VP equations is limited by the rapid increase of the number of resolution elements (grid points and/or particles) which is required to simulate an ever growing range of scales. Recent studies showed an interesting mapping of the 6-dimensional+ 1 (6D+1) VP problem into a more amenable 3D+1 non-linear Schrödinger-Poisson (SP) problem for simulating the evolution of DM perturbations. This opens up the possibility of improving the scaling of time propagation simulations using quantum computing. In this poster, we present a rigorous formulation of a variational-time evolution quantum algorithm for the simulation of the SP equations to follow DM perturbations, providing a thorough analysis of the scaling of the algorithm as a function of spatial dimensions and resolution. Finally we investigate the transition of the SP dynamics towards the classical limit, which could become an efficient alternative to the solution of the VP equation.

Energy derivatives with a fully differentiable Quantum Phase Estimation algorithm

Davide Castaldo - University of Padova

Quantum computing and differentiable programming are rapidly emerging among the quantum chemistry community as powerful techniques to speed up full-fledged quantum simulations. In order to take genuine advantage of these tools it is mandatory to refine existing algorithms to capture the complexity of chemical systems going well beyond the calculation of molecular energies. Here we report on the extension of a fully quantum differentiable pipeline to compute energy derivatives backpropagating through Quantum Phase Estimation (QPE) circuits. Such an implementation makes geometry optimizations, frequencies and molecular properties' calculations straightforward in a fault-tolerant setting where the QPE algorithm is one of the most promising alternatives. Building on the work of Cruz et al. we provide a statistical analysis on a smooth energy estimator that allows differentiability of the quantum subroutine. We tested our implementation on the H3+ and formaldehyde molecules performing both ground and excited state geometry optimization.

Tensor Network Simulations of a 2D SU(2) Yang-Mills Lattice Gauge Theory

Giovanni Cataldi - University of Padova

We demonstrate the feasibility of Tensor Network simulations of non-Abelian lattice gauge theo- ries in two spatial dimensions, by focusing on a (minimally truncated) SU(2) Yang-Mills model in Hamiltonian formulation, including dynamical matter. Thanks to our sign-problem-free approach, we characterize the phase diagram of the model at zero and finite baryon number, as a function of the bare mass and color charge of the quarks. Already at intermediate system sizes, we distinctly detect a liquid phase of quark-pair bound-state quasi-particles (baryons), whose mass is finite towards the continuum limit. Interesting phenomena arise at the transition boundary where color-electric and colo- magnetic terms are maximally frustrated: for low quark masses, we see traces of potential deconfinement, while for high quark masses, we observe signatures of a possible topological order. .

A General Approach to Dropout in Quantum Neural Networks

Andrea Ceschini - University of Rome La Sapienza

In classical Machine Learning, "overfitting" is the phenomenon occurring when a given model learns the training data excessively well, and it thus performs poorly on unseen data. A commonly employed technique in Machine Learning is the so called "dropout", which prevents computational units from becoming too specialized, hence reducing the risk of overfitting. With the advent of Quantum Neural Networks as learning models, overfitting might soon become an issue, owing to the increasing depth of quantum circuits as well as multiple embedding of classical features, which are employed to give the computational nonlinearity. Here we present a generalized approach to apply the dropout technique in Quantum Neural Network models, defining and analysing different quantum dropout strategies to avoid overfitting and achieve a high level of generalization. Our study allows to envision the power of quantum dropout in enabling generalization, providing useful guidelines on determining the maximal dropout probability for a given model, based on overparametrization theory. It also highlights how quantum dropout does not impact the features of the Quantum Neural Networks model, such as expressibility and entanglement. All these conclusions are supported by extensive numerical simulations, and may pave the way to efficiently employing deep Quantum Machine Learning models based on state-of-the-art Quantum Neural Networks.

Quantum spin models for numerosity perception

Maria Luisa Chiofalo - University of Pisa

Humans share with animals, both vertebrates and invertebrates, the capacity to sense the number of items in their environment already at birth. The pervasiveness of this skill across the animal kingdom suggests that it should emerge in very simple populations of neurons. Current modelling literature, however, has struggled to provide a simple architecture carrying out this task, with most proposals suggesting the emergence of number sense in multi-layered complex neural networks, and typically requiring supervised learning. Simple accumulator models fail to predict Weber's Law, a common trait of human and animal numerosity processing challenging to be simulated, stating that the only about 15% error-rate is proportional to the number of perceived items (up to 200), while the items uncertainty is Poissonian. In a quantum and neuro-science truly interdisciplinary research, we found that an open quantum spin network, mapping a neural system and equipped with all-to-all connectivity, can simulate the human sense of number as a global dynamical property. We use the quantum-like paradigm combined with a simulational approach borrowed from the theory and methods of open quantum systems out of equilibrium, to describe information processing in neural systems. OWr method is able to capture many of the perceptual characteristics of numerosity in such systems and account for Weber's law for the untrained quantum network. We finally present a first extensive study of the network connectivity conditions under which the counting capability is preserved, and discuss the perspectives of this promising approach to describe other perceptual phenomena connected with time and space.

VQE algorithm for topological one-dimensional many-body systems

Carola Ciaramelletti - University of L' Aquila

Among the many applications of quantum computation, there is the possibility to study more efficiently many- body systems and their properties. In this work I focus on systems that exhibit topological behavior, which that have attracted great attention in contemporary condensed matter physics due to their theoretical interest and technological potentiality. The aim of this work is the study of Su-Schrieffer-Heeger (SSH) and Kitaev fermonic open chains, which are the simplest models showing topological behavior, with the use of Variational Quantum Eigensolver (VQE) algorithm. The goal is to classify the topological phases through the identification of the topological ground state of the systems using topological properties, by implementing suitable objective functions for the algorithm in order to guide its convergence to the minimum energy state in the topologically non-trivial phase, where VQE fails due to the degeneracy caused by the presence of localized edge states at zero energy. This work is intended as starting point for the investigation of nontrivial interacting systems by quantum computers.

Digital simulation of a 1D spin chain in qudits

Edmunds Claire - Innsbruck University

Digital quantum simulation is an exciting near-term application of NISQ quantum devices. The re-programmable digital approach allows them to emulate a wide range of interesting materials, such as topological matter or large molecules, that have proven too complex to understand using classical physics and standard computation. Digital simulation combines the tool-set of quantum information with high performance gate-based evolution, enabling the use of quantum control and error mitigation protocols designed for gate-based algorithms. The high fidelities and long coherence times of trapped ion systems make them an excellent candidate to demonstrate digital quantum simulation. Here we will demonstrate the quantum simulation of a topological spin chain on a trapped-ion quantum processor. In this work, we utilize qudits to directly simulate higher-dimensional spin systems in nature. We generate the spin chain sequentially using an ancilla qubit and verify the expected properties of the state. In particular, we probe error-robust edge modes that arise due to topological symmetry in our material, and study the correlations and entanglement behaviour between qudits.

A Quantum Algorithm from Response Theory: Digital Quantum Simulation of Two-Dimensional Electronic Spectroscopy

Federico Gallina - University of Padova

Multidimensional optical spectroscopies are powerful techniques to investigate energy transfer pathways in natural and artificial systems. Because of the high information content of the spectra, numerical simulations of the optical response are of primary importance to assist the interpretation of spectral features. However, the increasing complexity of the investigated systems and their quantum dynamics calls for the development of novel simulation strategies. In our research, we considered using digital quantum computers. By combining quantum dynamical simulation and nonlinear response theory, we present a quantum algorithm for computing the optical response of molecular systems. The protocol has been tested on a near-term quantum device providing digital quantum simulation of the linear and nonlinear response of simple molecular models. The potential quantum advantage stems from the efficient quantum simulation of the dynamics governed by the molecular Hamiltonian.

Quantum operations in the ultrastrong coupling regime

Giuseppe Falci - University of Catania

We exploit dynamics and state processing of systems of superconducting artificial atoms ultrastrongly coupled to electric resonators. Quantum tasks such as the detection of virtual photons and adiabatic quantum operations will be addressed.

Quantum Convolutional Neural Networks for the detection of Gamma-Ray Bursts in the AGILE space mission data

Farida Farsian - INAF

Quantum computing represents a cutting-edge frontier in artificial intelligence, proposing to further enhance machine learning and deep learning techniques. Quantum Machine Learning algorithms, based on hybrid quantum-classical computation, try to leverage quantum mechanic principles, such as superposition, entanglement and interference which allow a different approach to machine learning detection problems. The work presented here falls within the context of the AGILE space mission, launched in 2007 by the Italian Space Agency. We implement different quantum deep learning algorithms that analyze data acquired by the instruments onboard AGILE to detect Gamma-Ray Bursts from sky maps or time series. In order to simulate the behaviour of a quantum computer, we use several frameworks such as TensorFlow-Quantum, PennyLane and Qiskit. We implement several Quantum Convolutional Neural Networks (QCNN), developing an embedding layer to represent classical data as quantum states. The results demonstrate that our QCNNs achieve almost the same accuracy as the classical counterparts but with far fewer parameters. We reached an accuracy of 0.951, while the classical counterpart achieved 0.984 on sky maps. The former uses only 51 parameters while the latter makes use of more than 100k parameters

Strategies to simulate dephasing-assisted quantum transport with digital quantum computers

Barbara Fresch - University of Padova

Simulating charge and energy transfer in extended molecular networks requires an effective model to include the environment because it significantly affects the quantum dynamics. A prototypical effect known as environment-assisted quantum transport (ENAQT) consists in the enhancement of the transfer efficiency by the interaction with an environment. A simple description of this phenomenon is obtained by a quantum master equation describing a quantum walk over the molecular network in the presence of inter-site decoherence. We consider the problem of simulating the dynamics underlying ENAQT in a digital quantum computer. Two different quantum algorithms are introduced, the first one based on stochastic Hamiltonians and the second one based on a collision scheme. Both algorithms can be implemented in a memory efficient encoding with the number of required qubits scaling logarithmically with the size of the simulated system while the number of gates increases quadratically. We discuss the algorithmic quantum trajectories generated by the two simulation strategies showing that they realize distinct unravellings of the site-dephasing master equation.

2+1 Dimensional QED with Quantum Computing

Karl Jansen - DESY, Center for Quantum Technologies and Applications

We give the current status of the project on 2+1-dimensional Quantum Electrodynamics (QED) combining quantum computing and classical Monte Carlo methods. The goal is to have a matching of physical quantities with the two techniques. We provide the Hamiltonian setup of a generic $N \times N$ QED system, preparing for an eventual quantum hardware run on the present NISQ devices. The final aim is to compute the running of the coupling and determine the lambda parameter of the theory.

Quantum TEA for QRydDemo - software stack to emulate a Rydberg quantum processing unit

Daniel Jaschke - University of Ulm / INFN Padova

The Quantum Tensor network Emulator Applications, i.e., Quantum TEA, offer simulation techniques from quantum circuits to the Schrödinger equation. The majority of the effort for the code development is currently hosted at the University of Padova and the INFN Padova. We demonstrate how the software stack based on Quantum TEA looks like for emulating a Rydberg quantum processing unit, which is currently being developed as QRydDemo project under the lead of the University of Stuttgart together with the University of Ulm and Toptica.

Tensor Networks for quantum circuits with hyper-optimized contraction methods

Giuseppe Magnifico - University of Bari

Tensor networks have emerged as one of the main computational tools for simulating quantum many-body systems, and their role has expanded to quantum computing. Following Google's claim of quantum supremacy with random quantum circuits, a series of works collectively showed the viability of simulating this task on classical supercomputers using hyper-optimized tensor network contractions. The purpose of this work is to develop a universal simulator of quantum circuits, combining state-of-the-art contraction methods with tensor-based algorithms, introducing finite fidelity. To achieve this, we first focus on exact simulations, showing results for circuits with up to 30 qubits. We compare different software solutions to contract tensor networks by testing them on random quantum circuits. This analysis aims at discerning the most suitable contraction method based on the number of qubits and layers.

Local basis reduction for lattice gauge theories contraction methods

Peter Majcen - University of Padova

For simulating lattice gauge theories with Tensor Network techniques, it is essential to truncate the local infinite-dimensional Hilbert space to perform numerical simulations. In this work, we introduce an approach where we perform this truncation not within the conventional Fock basis but instead employ the basis derived from cluster mean-field theory, to obtain a more efficient representation of the theory.

Quantum simulation with qudits

Michael Meth - Innsbruck University

Quantum simulators are a promising tool to study problems that are classically intractable. The problem of interest is encoded in the quantum state of a collection of qubits. However, nature is rarely binary and thus efficient quantum simulators ought to support higher dimensional hilbert spaces natively. We discuss the trapped-ion qudit simulator platform and its application to lattice gauge theories.

Integrated photonics in ion traps for scalable quantum information processing

Carmelo Mordini - ETH Zürich

The integration of photonic components in surface electrode traps is a promising approach for scalable quantum computing with trapped ions. They enable efficient delivery of laser light to the trap chip and scalably reproduce a beam configuration in different zones of the trap. Here we report on the last years of research endeavors on integrated photonics at ETH Zurich. We focused on surface electrode traps, equipped with integrated waveguides and diffractive output couplers made of silicon nitride, for controlling individual Calcium ion qubits. We demonstrated the first two-qubit entangling gate controlled by integrated light in a trap, and we currently explore the use of integrated design to tailor laser-ion information with a standing wave of light. Finally, adding real-time control of the trapping potential, we explore the use of such devices for scalable multizone quantum operations, where integrated light is used to distribute operations to multiple regions of the same trap chip.

Analysing crosstalk with the digital twin of a Rydberg atom QPU

Alice Pagano - University of Padova

Decoherence and crosstalk are two adversaries when aiming to parallelize a quantum algorithm: on the one hand, the execution of gates in parallel reduces decoherence due to a shorter runtime, but on the other hand, parallel gates in close proximity are vulnerable to crosstalk. This challenge is visible in Rydberg atom quantum computers where atoms experience strong van der Waals interactions decaying with distance. We demonstrate how the preparation of a 64-qubit GHZ state is affected by crosstalk in the closed system with the help of a tensor network digital twin of a Rydberg atom QPU. Then, we compare the error from crosstalk to the decoherence effects proving the necessity to parallelize algorithms.

Assessing how the structure of the QUBO problem affects the effectiveness of quantum annealing

Riccardo Pellini - Politecnico di Milano

In recent years there has been significant interest in exploring the potential of Quantum Annealers (QA) as heuristic methods to solve Quadratic Unconstrained Binary Optimization (QUBO) problems. It is known that some problems are more difficult to solve effectively on a QA compared to others. However, studying this analytically is very challenging unless the problem is small and it is often not clear how to use these findings to develop new general QUBO formulations that are easier to solve on QA. This work studies with an empirical perspective the characteristics making a QUBO problem difficult to solve on QA when it requires too many qubits for the analytical study of the Hamiltonian. We consider the Maximum Cut, Minimum Vertex Cover, Graph Coloring, Set Partitioning, Number Partitioning problems with instances requiring 30-32 QUBO variables, corresponding to 100-150 qubits. For all instances we compute several features based on the energy distribution of their solutions and on the spectral representation of the QUBO problem as a graph. Each instance is solved with the D-Wave Advantage QA, Simulated Annealing and Tabu Search. The problem instances are clustered based on their features and the clusters validated with Silhouette Coefficient and Elbow. The analysis reveals correlations between the clusters and the ability of QA to solve the instances effectively. Furthermore, we evaluate if these findings generalize to other problems, in particular for a Feature Selection problem. These results open new research opportunities to develop better QUBO formulations that are easier to solve on QA.

Dynamical Quantum Phase Transitions of the Schwinger Model: Real-Time Dynamics on IBM Quantum

Domenico Pomarico - University of Bari/INFN Bari

Simulating the real-time dynamics of gauge theories represents a paradigmatic use case to test the hardware capabilities of a quantum computer, since it can involve non-trivial input states' preparation, discretized time evolution, long-distance entanglement, and measurement in a noisy environment. We implemented an algorithm to simulate the real-time dynamics of a few-qubit system that approximates the Schwinger model in the framework of lattice gauge theories, with specific attention to the occurrence of a dynamical quantum phase transition. Limitations in the simulation capabilities on IBM Quantum were imposed by noise affecting the application of single-qubit and two-qubit gates, which combine in the decomposition of Trotter evolution. The experimental results collected in quantum algorithm runs on IBM Quantum were compared with noise models to characterize the performance in the absence of error mitigation.

Parent Hamiltonian reconstruction via inverse quantum annealing

Davide Rattacaso - University of Padova

Finding a local Hamiltonian with a specific many-body wave function as its ground state poses a substantial computational challenge. Solving this challenge can have a profound impact on advancing quantum technologies, ranging from benchmarking quantum devices to facilitating quantum state preparation. We present a novel method, inspired by quantum annealing, designed to address this task through artificial inverse dynamics. By slowly deforming the state, we induce an adiabatic evolution of the corresponding Hamiltonian. We name this approach "inverse quantum annealing" (IQA). In cases where long-range correlations are absent, the Hamiltonian generated through adiabatic evolution well approximated a solution for our inverse problem. Notably, IQA allows for an efficient numerical implementation, relying solely on the knowledge of local expectation values. To validate our approach, we apply inverse quantum annealing to discover a local Hamiltonian for two paradigmatic models and various system sizes. This exploration also allows us to investigate the effects of long-range correlations and traversing different-order phase transitions

Tree Tensor Networks for quantum systems at finite temperature

Nora Reinič - University of Padova

Since a physical system can never be cooled down to absolute zero temperature, a complete description of the physics behind the quantum computing devices has to account for finite temperature effects. However, the finite temperature, i.e. mixed state scenario, represents an additional challenge in comparison to the already computationally demanding zero-temperature quantum many-body simulations. Within the tensor network framework, we develop and implement an efficient Tree Tensor Network based algorithm for computing the finite temperature many-body density matrix. We present the numerical techniques for computing the purity, entropy, as well as entanglement properties of the mixed state systems. Our approach is successfully applied to one-dimensional quantum Ising model, and moreover, to the systems of neutral Rydberg atoms trapped in the optical tweezer arrays, representing a physical quantum computing and simulation platform.

Two-way communication between high-energy physics and quantum matter

Enrique Rico Ortega - University of the Basque Country (UPV/EHU) & Ikerbasque

We will present the results of an interdisciplinary collaboration between groups working in high-energy physics and quantum matter during these last years. First, we will show how it is possible to do the "Quantum Simulation of Light-Front Parton Correlators"[Phys. Rev. D 104, 014512 (2021)] where quantum technologies can help to calculate ab initio correlators that characterize non-perturbative aspects of QCD. Second, we will show how enters the "Role of anomalous symmetry in $0-\pi$ qubits" [Phys. Rev. B 105, L201104 (2022)] and how the notion of the anomaly explains the robustness of this qubit to decoherence. To conclude, we will present an efficient and deterministic protocol to prepare the ground state of non-trivial lattice gauge models even in the presence of noise: "Noise-aware variational eigensolvers: a dissipative route for lattice gauge theories".

(1+1)D QCD via Tensor Networks

Marco Rigobello - University of Padova

We study 2-flavor Hamiltonian lattice QCD in (1+1)D with hardcore gluons, at zero and finite density, by means of matrix product states. We introduce a formulation of the theory where gauge redundancy is absent and construct a gauge invariant tensor network ansatz. We show that the model is critical in an extended subregion of parameter space and identify at least two distinct phases, one of which embeds the continuum limit location. We reconstruct a subset of the particle spectrum in each phase, identifying edge and bulk gapless modes. We thereby show that the studied model provides a minimal SU(3) gauge theory whilst reproducing known phenomena of (3+1)D QCD. Most notably, it features charged pions.

Quantum Effects in Josephson Junctions

Luca Salasnich / Koichiro Furutani - University of Padova / INFN Padova

We theoretically investigate the dynamics of both superconducting and atomic Josephson junctions under the effect of a quantum-thermal bath. In the case of resistively and capacitively shunted Josephson junctions the stochastic bath is due to the Ohmic noise of the resistor, while in the case of elongated quasi one dimensional atomic Josephson junctions the stochastic bath is due to the incoherent and dissipative behavior of non-condensed atoms. We investigate the correlation function of Josephson phase finding an earlier decay of coherence at high temperatures, where thermal fluctuations dominate over quantum ones. Finally, by using the path-integral formalism with relative phase and population imbalance as dynamical variables, we derive an effective only-phase action for the bosonic Josephson junction performing functional integration over the population imbalance. In this way, we obtain zero-temperature quantum corrections to the mean-field Josephson frequency of oscillation.

A Benchmark Study of Adaptative Variational Quantum Algorithms on QUBO Instances

Madhumita Sarkar - Jožef Stefan Institute

Adaptative Variational Quantum Algorithms (adaptative VQAs) represent a significant advancement over traditional Variational Quantum Algorithms (VQAs). Differently from fixed-structure VQAs, adaptative VQAs not only optimize gate parameters, but also dynamically modify the circuit structure by adding or removing gates during the training process. These algorithms overcome limitations of traditional VQAs, enabling them to adapt to specific problem domains and available hardware configurations. However, despite the existence of various adaptative VQAs, a systematic comparison among these methods is still lacking in the literature. Therefore, our study aims to fill this gap by analyzing three specific adaptative algorithms: Evolutionary Variational Quantum Eigensolver (EVQE), Variable Ansatz (VAns), and Random Adapt-VQE (RA-VQE), where the latter is introduced as a baseline. Additionally, we include the Quantum Approximate Optimization Algorithm (QAOA) in our analysis to compare the adaptative algorithms with traditional VQAs. Our evaluation involves applying these algorithms to QUBO problems and assessing the quality of the results in terms of approximation ratio, number of gates, and computational time required. Furthermore, we investigate the influence of the hyperparameters and propose a Bayesian approach to select them effectively. Our analysis reveals that, with carefully chosen hyperparameters, all of these algorithms produce high-quality solutions with similar approximation ratios. However, the number of gates in the final circuit and the associated computational costs can differ significantly between the approaches. Therefore, we conclude that an evaluation based only on the approximation ratio is insufficient, and other dimensions should be considered for a more accurate representation of how these methods perform.

Manipulating exciton binding by floquet engineering in Fermi Hubbard Model

Madhumita Sarkar - Jožef Stefan Institute

Strong excitations of correlated quantum materials give rise to various non-thermal phases which are not present in their equilibrium counterpart. Recently, it was shown that the one-dimensional Fermi Hubbard Model features charge density wave and η-pairing phases upon photo-doping. In this study, we explore the non-equilibrium behavior of the Fermi Hubbard ladder and employ the Schrieffer-Wolff transformation to map it to a simplified t-J-like model, providing an effective equilibrium description of the photo-doped states. Our investigation highlights the significance of an additional η-exchange coupling between exciton pairs in the presence of doublons. We find the dependence of binding

energy of excitons on exchange couplings and show that the application of an electric field along the rung to the hopping term enhances exciton pairing. This floquet manipulation allows to manipulate the strength of hopping and exchange parameters independently. This is responsible for increasing the binding energy. To characterize the ground state of the system, we employ relevant correlators and make notable observations. We show that at strong anisotropy, the ground state encompasses a strongly bound doublon-holon pair along the rung, alongside inter-chain singlets. Additionally, we propose experimental setups to test the predictions put forth by our theory.

A Benchmark Study of Adaptative Variational Quantum Algorithms on QUBO Instances

Gloria Turati - Politecnico di Milano

Adaptative Variational Quantum Algorithms (adaptative VQAs) represent a significant advancement over traditional Variational Quantum Algorithms (VQAs). Differently from fixed-structure VQAs, adaptative VQAs not only optimize gate parameters, but also dynamically modify the circuit structure by adding or removing gates during the training process. These algorithms overcome limitations of traditional VQAs, enabling them to adapt to specific problem domains and available hardware configurations. However, despite the existence of various adaptative VQAs, a systematic comparison among these methods is still lacking in the literature. Therefore, our study aims to fill this gap by analyzing three specific adaptative algorithms: Evolutionary Variational Quantum Eigensolver (EVQE), Variable Ansatz (VAns), and Random Adapt-VQE (RA-VQE), where the latter is introduced as a baseline. Additionally, we include the Quantum Approximate Optimization Algorithm (QAOA) in our analysis to compare the adaptative algorithms with traditional VQAs. Our evaluation involves applying these algorithms to QUBO problems and assessing the quality of the results in terms of approximation ratio, number of gates, and computational time required. Furthermore, we investigate the influence of the hyperparameters and propose a Bayesian approach to select them effectively. Our analysis reveals that, with carefully chosen hyperparameters, all of these algorithms produce high-quality solutions with similar approximation ratios. However, the number of gates in the final circuit and the associated computational costs can differ significantly between the approaches. Therefore, we conclude that an evaluation based only on the approximation ratio is insufficient, and other dimensions should be considered for a more accurate representation of how these methods perform.

List of industrial talks

Quantum Computing for Earth Observation: A Space Sector Industry perspective

Tommaso Catuogno - Thales

Quantum Computing (QC) promises to revolutionize most industrial sectors that, for the specific peculiarities of their computational problems, will benefit from the substantial computational performance increases that the adoption of a QC approach will deliver. Among these sectors, the Space based Earth Observation (EO) one is rich of computationally hard problems that can be potentially solved with this innovative computing paradigm. In this context, Thales Alenia Space, Domain Observation and Navigation is working to understand the most promising EO applications that could benefit from hybrid quantum-classical architectures within next 15 years, strictly working with academic institutions and companies all over Europe. The presentation will showcase the work activities that are planned and ongoing by Thales Alenia Space in the field.

Quantum Computing for Fraud Detection and Credit Scoring

Davide Corbelletto - Intesa San Paolo

Since its foundation in 2020, the Quantum Competence Center of Intesa Sanpaolo has been pursuing the industrial research on Quantum Computing applied to financial applications. Therefore, it was natural for our organization to join the Spoke 10 within the "National Research Center on HPC, Big Data, and Quantum Computing" and apply for a couple of project ideas subsidized by the Innovation Funds which have both been recently approved: Fraud Detection and Credit Scoring. The aim of these two initiatives is to experiment with new algorithms that allows to better detect anomalies and more carefully categorize borrowers, respectively enhancing transaction security and improving financial inclusion.

Tackling Partial Differential Equations in Industry with Quantum Computers: A Collaborative Initiative

Daniele Dragoni - Leonardo S.p.A.

Quantum Computers can perform operations on vectors in exponentially large vector spaces in polynomial time. This opens up the possibility of solving problems that are infeasible for classical computers. As part of the initiatives established by the "National Research Center on HPC, Big Data, and Quantum Computing", we plan to investigate the potential capabilities of quantum computers in solving linear and non-linear partial differential equations. The study is a collaborative effort involving various industrial and academic partners, and will focus on two industrial applications: the modeling of fluid dynamics via Navier-Stokes equations and the modeling of electromagnetic wave propagation via Maxwell equations.

Driving Quantum Innovation in Italy: Fostering a Precompetitive Ecosystem

The role of the Quantum Computing & Communication Observatory of the Politecnico di Milano

Marina Natalucci - Politecnico di Milano

In a world where Quantum Technologies could radically transform information technology, with wide-ranging potential impacts on competitiveness and national security, exchanging ideas and a common knowledge base becomes crucial.

The Observatory of the Politecnico di Milano, born in 2020, aims at being a reliable reference point for Quantum Computing & Communication in Italy. The initiative promotes a pre-competitive ecosystem, involving a community of both demand and supply companies - active or interested in the topic - and experts at Italian and international levels. In this environment, people can share business experiences, discuss use cases and areas of application of these technologies, as well as the difficulties they face in introducing them into the company.

In Italy, the path towards Quantum Computing is still in its infancy; a survey from the Observatory shows that only 50% of the 106 large Italian companies interviewed have at least a minimal knowledge of it. The delay in governmental commitment has indeed slowed down awareness of these themes. Nevertheless, there are cutting-edge research initiatives and companies determined to be forerunners of the technology: Observatory's research reveals more than 20 projects on Quantum Computing in Italian companies.

The time horizon for the production use of quantum computing is undoubtedly long, but it requires a systemic change, equally long and challenging to undertake. The companies interviewed stated that the lack of relevant skills, the difficulty of identifying use cases, and the complexity of quantifying return on investment remain the main challenges in pursuing this path.

Quantum Computing in the energy sector: looking for applications across the whole value chain

Alessia Marruzzo - Eni S.p.A.

In ENI we have been looking at High Performance Computing (HPC) applied to the energy sector since more than 10 years now. We invest in the development of our own proprietary codes and we constantly look at new solutions to improve the efficiency in whole our value chain. Within these experiments we started to look at Quantum Computing in 2018. Since then, we have carried out several projects in collaborations with research institutions and start-up. All these projects had the main purpose of testing the technology and trying to understand which applications make the most sense to look at. Our participation in Spoke 10 gave us the opportunity to speed up the testing on this technology. We submitted two projects: Quantum algorithms for the solution of differential equations and Molecular Energy Landscapes by Quantum Computing - Benchmark calculations. In the first project we aim at understating the potentialities of Quantum algorithms for the solution of large systems of differential equations that arise applying the Finite Element method for the modellization of fluid dynamics. In 2009 Harrow, Hassidim and Lloyd introduced an algorithm, later improved by other authors, that gives and exponential speedup in respect to classical algorithms. Algorithms for the solution of linear system of equations have a wide spectrum of applications. The aim of the second project is testing the feasibility of quantum computing to obtain molecular energies and wavefunctions in important chemical reactions. We plan to adopt methods capable of describing electron correlation in near-degenerate situations, that typically occur when reactants transform into products, in labile intermediates, or in transition metals (important for catalysis and magnetism). The target use case concerns the styrene polymerization.

Cybersecurity and Combinatorial Optimization

Alessia Perissinotto - Autostrade per l'Italia