Ying-Jer Kao [National Taiwan University]

Symmetric tensor network studies of Kitaev spin liquids

We study the spin-1/2 star and spin-1 honeycomb Kitaev models using ℤ_2 invariant Projected Entangled Pair States (PEPS). We find that the transition from Abelian to non-Abelian phase of the star lattice Kitaev model can be understood as charge and flux transmuting into σ anyon in the ℤ_2 invariant PEPS framework. Besides, we show that the ground state always has infinite correlation length in the non-Abelian regime, consistent with the no-go theorem that a chiral PEPS has a gapless parent Hamiltonian. On the other hand, we confirm the ℤ_2 spin liquid nature of isotopic spin-1 Kitaev honeycomb model by evaluating the virtual order parameters defined on the virtual Hilbert space of the tensor network. Using the correspondence between the transfer matrix spectrum and low-lying excitations, we find that contrary to the dispersive Majorana excitation in the spin-1/2 case, the system has a dispersive charge anyon excitation. Bottom of the gapped single-particle charge anon excitations are also identified with the corresponding correlation length $\xi \approx 6.7$ unit cells.

Atsushi Iwaki [University of Tokyo]
Thermal pure quantum matrix product states: Sample efficiency and Random fluctuation

Thermal pure quantum matrix product state (TPQ-MPS) is a microscopic description of a nearly pure quantum state at finite temperature based on the matrix product representation with the auxiliary sites placed on the edges of the system as entanglement bath. The state carries an entanglement entropy that follows a volume law up to the whole system size [1]. However, a general description of a finite temperature many-body state often relies on the mixture of pure states where a volume-law entropy that cannot be fully captured by a single pure state can be recovered by the classical ensemble. Although the degree of the mixture shall have relevance to the purity of the quantum state, the measure of purity that can be applied to a general mixed state was lacking. We focus on the efficiency of the random sampling method proposed in Ref.[2], which could measure the number of required sample averages or the degree of mixture. By transforming the efficiency, we develop a formula that can measure the purity of the quantum many-body mixed state explicitly by using a physically meaningful observable.
[1] A. Iwaki, A. Shimizu, and C. Hotta, PRResearch 3, L022015 (2021).
[2] S. Goto, R. Kaneko, and I. Danshita, PRB 104, 045133 (2021).

Wei Tang [Ghent University]
Continuous matrix product operator approach to finite temperature quantum states and its application to the nonlinear sigma model with $¥theta=¥pi$ term

In the first part of our presentation, we will present a tensor network algorithm that simulates the one-dimensional and quasi-one-dimensional systems at the thermodynamic limit. Using the continuous matrix product operator (cMPO) representation for the partition function, the approach handles both short-range and long-range interactions in the thermodynamic limit without incurring any time discretization error. Besides ordinary thermodynamic quantities, this approach can be used to calculate the imaginary-time correlation functions and local dynamical quantities, the latter of which can be observed in nuclear magnetic resonance experiments. In the second part of our presentation, we employ the cMPO method to the $(1+1)$-dimensional $O(3)$ nonlinear $¥sigma$-model with $¥theta=¥pi$ term. Within the Hamiltonian formulation, this field theory emerges as the finite-temperature partition function of a modified quantum rotor model decorated with magnetic monopoles. Using the monopole harmonics basis, we derive the matrix representation for this modified quantum rotor model, which enables tensor network simulations. Using the cMPO method, we study the finite-temperature properties of this model and reveal its massless nature. The central charge as a function of the coupling constant is directly extracted in our calculations and compared with field theory predictions.

Lei Wang [Institute of Physics, Chinese Academy of Science]
Neural canonical transformation for m* of two-dimensional electron gas

The quasiparticle effective mass m* of interacting electrons is a fundamental quantity in the Fermi liquid theory. However, the precise value of the effective mass of uniform electron gas is still elusive after decades of research. The newly developed neural canonical transformation approach [Xie et al., 2105.08644] offers a principled way to extract the effective mass of electron gas by directly calculating the thermal entropy at low temperature. The approach models a variational many-electron density matrix using two generative neural networks: an autoregressive model for momentum occupation and a normalizing flow for electron coordinates. Our calculation reveals a suppression of effective mass in the two-dimensional spin-polarized electron gas, which is more pronounced than previous reports in the low-density strong-coupling region. This prediction calls for verification in two-dimensional electron gas experiments.

Ref: Hao Xie, Linfeng Zhang, Lei Wang, arXiv:2201.03156

Ian McCulloch [University of Queensland]

Exponents and Scaling at Dynamical Quantum Critical Points

A Dynamical Quantum Critical Point (DQPT) is a relatively recent notion whereby a global quench of a quantum state induces a sequence of critical points (meaning non-analytic behaviour of the boundary partition function) as a function of time. I will present an algorithm for calculating the higher moments of the Loschmidt Echo for a translationally invariant infinite MPS and show how it can be used to probe universal behaviour of DQPTs, focussing on the phase of the Loschmidt Amplitude, which has been somewhat neglected in the past.

Kevin Slagle [Caltech]

Fast Tensor Disentangling Algorithm and Emergent Quantum Mechanics from a Stochastic Tensor Network

In the first part of this talk, I describe a fast non-iterative algorithm to approximately disentangle a tensor. I also provide pictorial intuition, demonstrate the algorithm's usefulness with numerical experiments, and mention future directions. (arXiv:2104.08283) In the second part, we use tensor networks to demonstrate that it is possible for quantum mechanics to emerge from classical mechanics. In particular, using a well-controlled perturbation theory and numerical simulations, we show that the time evolution of any quantum mechanics Hamiltonian can be realized at the boundary of a stochastic tensor network with local dynamics.

Saeed Jahromi [Institute for Advanced Studies in Basic Sciences (IASBS)]
Graph-based projected entangled-pair state for any infinite lattice

We present a general graph-based Projected Entangled-Pair State (gPEPS) algorithm to approximate both ground states and thermal states of nearest-neighbor local Hamiltonians on any lattice or graph of infinite size. By introducing the structural-matrix which codifies the details of tensor networks on any graphs in any dimension d, we are able to produce a code that can be essentially launched to simulate any lattice. We further introduce an optimized algorithm to compute simple tensor updates as well as expectation values and correlators with a mean-field-like effective environments for both zero- and finite-temperature. Though not being variational, this strategy allows to cope with PEPS of very large bond dimension (e.g., D=100), and produces remarkably accurate results in the thermodynamic limit in many situations, and specially when the correlation length is small and the connectivity of the lattice is large. We present several benchmarck results to show the accuracy and efficiency of our methods.

Henrik Dreyer [Cambridge Quantum]
Robustness of critical U(1) spin liquids and emergent symmetries in tensor networks

We study the response of critical Resonating Valence Bond (RVB) spin liquids to doping with longer-range singlets, and more generally of U(1)-symmetric tensor networks to non-symmetric perturbations. Using a field theory description, we find that in the RVB, doping constitutes a relevant perturbation which immediately opens up a gap, contrary to previous observations. Our analysis predicts a very large correlation length even at significant doping, which we verify using high-accuracy numerical simulations. This emphasizes the need for careful analysis, but also justifies the use of such states as a variational ansatz for critical systems. Finally, we give an example of a PEPS where non-symmetric perturbations do not open up a gap and the U(1) symmetry re-emerges.
Based on https://arxiv.org/abs/2008.04833

Chia-Min Chung [National Sun Yat-Sen University]

Stripes and superconductivity in the two-dimensional Hubbard model

The two-dimensional (2D) Hubbard model is a fundamental model in understanding superconductivity in cuprates. By implying density matrix renormalization group and quantum Monte Carlo methods, we carefully study the ground state properties of 2D Hubbard model and t'-Hubbard model. We especially focus on the so-called stripe order, and its competition to superconductivity.

Ryui Kaneko [Kindai University]

Tensor-network study of correlation-spreading dynamics in two-dimensional systems

We analyze real-time dynamics of the two-dimensional Bose-Hubbard model after a sudden quench starting from the Mott insulator by means of the two-dimensional tensor-network method [R. Kaneko and I. Danshita, arXiv:2108.11051].Calculated single-particle correlation functions are found to be in good agreement with a recent experiment [Y. Takasu et al., Sci. Adv. 6, eaba9255 (2020)], which cross validates the experiment and the numerical simulation. By estimating the phase and group velocities from the single-particle and density-density correlation functions, we predict how these velocities vary in the moderate interaction region, which will be useful for future experiments. If time allows, we will also discuss the quench dynamics of the two-dimensional quantum Ising model recently realized in the Rydberg atom arrays.

Masazumi Honda [Yukawa Institute]

Digital quantum simulation of higher-charge Schwinger model with topological term

I am going to talk about application of quantum computation to numerical simulation of quantum field theory. Specifically, we implement a digital quantum simulation of a gauge theory with a topological term in Minkowski spacetime, which is practically inaccessible by standard lattice Monte Carlo simulations. We focus on 1+1 dimensional quantum electrodynamics with a topological term and a charge-q Dirac fermion known as the Schwinger model. We construct the true vacuum state of a lattice Schwinger model using adiabatic state preparation which, in turn, allows us to compute an expectation value of the fermion mass operator with respect to the vacuum. Upon taking a continuum limit we find that our result in massless case agrees with the known exact result. In massive case, we find an agreement with mass perturbation theory in small mass regime and deviations in large mass regime. We also study a potential between heavy charged particles and see that the potential changes its qualitative behavior as changing parameters: it shows confinement, screening and an exotic behavior called negative tension behavior in which particles with opposite charges repel with each other.

[1] B.Chakraborty, M. Honda, T. Izubuchi, Y. Kikuchi and A. Tomiya, arXiv:2001.00485

[2] M. Honda, E. Itou, Y. Kikuchi, L. Nagano and T. Okuda, arXiv:2105.03276

[3] M. Honda, E. Itou, Y. Kikuchi and Y. Tanizaki arXiv:2110.14105

Yang Liu [Institute of Physics, Chinese Academy of Sciences]
Numerical research of excitations of two dimensional magnetic lattice based on PEPS

Ryotaro Suzuki [Freie Universität Berlin]
Computational power of one- and two-dimensional dual-unitary quantum circuits

"Quantum circuits that are classically simulatable tell us when quantum computation becomes less powerful than or equivalent to classical computation. Such classically simulatable circuits are of importance because they illustrate what makes universal quantum computation different from classical computers. I will talk about our recent proposal on classically simulatable circuits by making use of dual-unitary quantum circuits, which have been recently investigated as exactly solvable models of non-equilibrium physics, and we characterize their computational power."

Sajant Anand [UC Berkeley]
Isometric Tensor Network States on an Infinite Strip

Contraction of standard 2D tensor network ansatzes relies on approximation schemes, as tensor contractions costs scale exponentially with system size. Recently, the Isometric Tensor Network (isoTNS) ansatz was introduced for 2D finite quantum systems on a square lattice, allowing for exact O(1) evaluation of expectation values provided we can efficiently move the orthogonality center throughout the network. Here we generalize this isoTNS ansatz to strip geometries, in which the networks are infinite by finite and consist of translationally invariant rows of tensors. We demonstrate several algorithms for the infinite Moses Move (iMM), which moves the orthogonality hypersurface between columns of infinite length in the network. Using these iMM algorithms, we perform imaginary time evolution to identify the ground state of our 2D system, where the cost of optimization scales linearly with strip width rather than exponentially.

Shinichiro Akiyama [Tsukuba University]
Tensor renormalization group approach to higher-dimensional lattice field theories

The tensor renormalization group (TRG) approach is a variant of the real-space renormalization group to evaluate the path integral in the thermodynamic limit, without resorting to any probabilistic interpretation for the given Boltzmann weight. Moreover, since the TRG can directly deal with the Grassmann variables, this approach can be formulated in the same manner for the systems with bosons, fermions, or both of them. These advantages of the TRG approach have been confirmed by earlier studies of various (2+1)- and (3+1)-dimensional lattice theories, which suggest that the TRG potentially enables us to investigate the parameter regimes where it is difficult to access with the standard stochastic numerical methods, such as the Monte Carlo simulation. In this talk, reviewing recent progress on the TRG algorithms, we explain their application to the Hubbard model at finite density and relativistic lattice fermions.

Runze Chi [Institute of Physics, Chinese Academy of Sciences]

Tensor-Network Study of the Excitation of the Triangular Lattice Antiferromagnetic XXZ Model

We calculate the excitation spectrum of the triangular antiferromagnetic XXZ model using the excitation iPEPS ansatz. The simulation results show similar characteristics with the experimental results. We find that the higher soft mode at the M point originates from two magnon branches in the zero-field which has not been pointed by the previous theory.

Hui-Ke Jin [Technische Universität München]

Matrix Product States for Hartree-Fock-Bogoliubov Wave Functions

We provide an efficient and accurate method for converting Hartree-Fock-Bogoliubov wave functions into matrix product states (MPSs). These wave functions, also known as "Bogoliubov vacua", exhibit a peculiar entanglement structure that the eigenvectors of the reduced density matrix are also Bogoliubov vacua. We exploit this important feature to obtain their optimal MPS approximation and derive an explicit formula for corresponding MPS matrices. The performance of our method is benchmarked with the Kitaev chain and the Majorana-Hubbard model on the honeycomb lattice. The approach facilitates the applications of Hartree-FockBogoliubov wave functions and is ideally suited for combining with the density-matrix renormalization group method.

Jozef Genzor [National Center for Theoretical Science, National Taiwan University]
J1-J2 Fractal by Multi-Recursion HOTRG

We develop a novel technique to investigate phase transition phenomena on self-similar lattices constructed on a square-lattice frame with two different coupling strengths, J1 and J2. By introducing two types of couplings, it is possible to continuously transform a regular square lattice into a fractal lattice by adjusting some couplings determined by the underlying fractal pattern. In extreme cases, a pure fractal lattice is obtained when specified bonds are cut by setting J2 = 0, and a regular square lattice is recovered when J1 = J2 = 1. Besides, when J1 < J2, a different fractal pattern is obtained that is "inverse" to the J1 > J2 case. We can perform measurements using impurity tensors in any regime, including a pure fractal lattice and regular square lattice. Instead of having one type of local tensor and one extension relation as in the Higher-Order Tensor Renormalization Group (HOTRG) algorithm (Ref. [1]), we introduce several types of local tensors, with each being extended by a different recursive relation. The recursive relations specify how to combine different tensors to extend the system size. For concreteness, we focus on the Ising model on fractal lattice introduced in Ref. [2] to compare with our method easily; however, our technique can be applied to a wide variety of fractal patterns. The computational cost scales with the bond dimension the same way as the HOTRG in two dimensions with a constant-factor overhead.
[1] Z.Y. Xie, J. Chen, M.P. Qin, J.W. Zhu, L.P. Yang, and T. Xiang,
Phys. Rev. B 86, 045139 (2012).
[2] J. Genzor, A. Gendiar, and T. Nishino, Phys. Rev. E 93, 012141 (2016).

Kotaro Tamaoka [Nihon University]
Pseudo entropy and its applications

Recent studies have shown an interesting connection between tensor networks, quantum gravity, and holography. For example, certain tensor networks can provide toy models of holography. In this talk, we will introduce "pseudo entropy", a holography-inspired generalization of the entanglement entropy. After reviewing backgrounds, we will discuss how we can find such a generalization from the viewpoint of holography. We will then discuss some applications to quantum many-body systems.

Rong-Yang Sun [RIKEN Center for Computational Science (R-CCS)]
Nematic quantum liquid state in the triangular-lattice SU(4) spin-orbital model

The simplest spin-orbital model can host a nematic spin-orbital liquid on the triangular lattice. We provide clear evidence that the ground state of the SU(4) Kugel-Khomskii model on the triangular lattice can be well described by a "single" Gutzwiller projected wave function with an emergent parton Fermi surface, despite it exhibits strong finite-size effect in quasi-one-dimensional cylinders. The finite-size effect can be resolved by the fact that the parton Fermi surface consists of open orbits in the reciprocal space. Thereby, a stripy liquid state is expected in the two-dimensional limit, which preserves the SU(4) symmetry while breaks the translational symmetry by doubling the unit cell along one of the lattice vector directions. It is indicative that these stripes are critical and the central charge is c = 3, in agreement with the SU(4) 1 Wess-Zumino-Witten conformal field theory. All these results are consistent with the Lieb-Schultz-Mattis-Oshikawa-Hastings theorem.

Roman Orus [DIPC / Multiverse Computing]
News on tensor network simulations for quantum matter and beyond

In this talk I will give a brief overview of some recent developments concerning tensor network methods for the simulation of quantum matter in my group. These include simulations of breathing Kagome antiferromagnets, 3d thermal bosons, 3d Kitaev models and 2d models with SU(2) symmetry.