Program

	Jul 10 (Mon)	Jul 11 (Tue)	Jul 12 (Wed)	Jul 13 (Thu)	Jul 14 (Fri)
Morning	Opening		Kenji Harada	Takafumi Suzuki	Ryui Kaneko
Afternoon	Satoshi Morita		Chia-Min Chung	Tsuyoshi Okubo	Naoki Kawashima

	Jul 17 (Mon)	Jul 18 (Tue)	Jul 19 (Wed)	Jul 20 (Thu)	Jul 21 (Fri)
Morning	Wei-Lin Tu	Ying-Jer Kao	Yun-Tak Oh	Synge Todo	Closing
Afternoon	Jheng-Wei Li	ShengHsuan Lin	Dong-Hee Kim	Hong-Hao Tu	

Ashkin-Teller phase transition and multicritical behavior in a classical monomer-dimer model

Satoshi Morita

We use Monte Carlo simulations and tensor network methods to study a classical monomer-dimer model on the square lattice with a hole (monomer) fugacity z, an aligning dimer-dimer interaction u that favors columnar order, and an attractive dimer-dimer interaction v between two adjacent dimers that lie on the same principal axis of the lattice. The Monte Carlo simulations of finite size systems rely on our grand-canonical generalization of the dimer worm algorithm, while the tensor network computations are based on a uniform matrix product ansatz for the eigenvector of the row-to-row transfer matrix, which work directly in the thermodynamic limit. The phase diagram has nematic, columnar order and fluid phases, and a nonzero temperature multicritical point at which all three meet. For any fixed $v/u<\infty$, we argue that this multicritical point continues to be located at a nonzero hole fugacity $z_{mc}(v/u)>0$; our numerical results confirm this theoretical expectation, but find that $z_{mc}(v/u)\to 0$ very rapidly as $v/u \to \infty$. Our numerical results also confirm the theoretical expectation that the corresponding multicritical behavior is in the universality class of the four-state Potts multicritical point on critical line of the two dimensional Ashkin-Teller model.

TBD

Kenji Harada

TBD

Matrix product state simulations of quantum quenches and transport in Coulomb blockaded superconducting devices

Chia-Min Chung

Superconducting devices subject to strong charging energy interactions and Coulomb blockade are one of the key elements for the development of nanoelectronics and constitute common building blocks of quantum computation platforms and topological superconducting setups. The study of their transport properties is nontrivial and some of their nonperturbative aspects are hard to capture with the most ordinary techniques. Here we present a matrix product state approach to simulate the real-time dynamics of these systems. We propose a study of their transport based on the analysis of the currents after quantum quenches connecting such devices with external leads. Our method is based on the combination of a Wilson chain construction for the leads and a mean-field BCS description for the superconducting scatterers. In particular, we employ a quasiparticle energy eigenbasis which greatly reduces their entanglement growth and we introduce an auxiliary degree of freedom to encode the device's total charge. This approach allows us to treat nonperturbatively both their charging energy and coupling with external electrodes. We show that our construction is able to describe the Coulomb diamond structure of a superconducting dot with subgap states, including its sequential tunneling and cotunneling features.

Quantum spin liquid in the Kitaev-Gamma model on a honeycomb lattice

Takafumi Suzuki

Magnetic properties of the honeycomb-lattice magnet, α-$RuCl_3$, have been much studied because of the possible realization of the Kitaev spin liquid. The Kitaev-Γ (KΓ) model on the honeycomb lattice has been proposed as a minimal model of this magnet. For the simplicity of problems, the equivalent coupling amplitude has been considered for the interactions on each bond constructing the honeycomb network. However, a good understanding of the nature of the ground state is still lacking. In this study, we extended the model to include an additional parameter that controls the coupling strength on one of the bonds. In this model, we connect the limit of isolated KΓ chains, which is known to exhibit an emergent SU(2) Tomonaga-Luttinger liquid (TLL) [2], to the isolated dimer model via the isotropically interacting two-dimensional model. We investigate the ground-state phase diagram by using numerical exact diagonalizations, density-matrix renormalization group methods, and cluster expansion methods. We find that TLL appearing in the chain limit persists for finite interchain couplings, when the Kitaev and Γ interactions are negative and positive, respectively. In this proximate TLL phase, the low-energy excitation is characterized by spinon-like gapless excitation, which is similar to that observed in S=1/2 antiferromagnetic Heisenberg chain [3]. The proximate TLL shows a direct phase transition to the paramagnetic state appearing in the isolated dimer limit. We also investigate the temperature dependence of the specific heat, C(T), in the proximate TLL phase. A double-peak structure similar to that in the Kitaev model develops near the isotropically interacting model. We find that the interchain interaction between the KΓ chains fails to explain the origin of the low-temperature peak.

[1] J. G. Rau, E. Lee, and H.-Y. Kee, Phys. Rev. Lett. 112, 077204 (2014).
[2] W. Yang, et al., Phys. Rev. Lett. 124, 147205 (2020).
[3] M. Gohlke, J. -C. Pelayo, and T. Suzuki, arXiv:2212.11000.

Quantum-classical entangled approach with tensor networks for spin liquid

Tsuyoshi Okubo

To represent a quantum many-body state, we need to treat huge vectors in exponentially increasing dimensions as we increase the number of particles. Such an exponentially large vector space is a fundamental difficulty in treating quantum many-body problems in classical computers. However, when we use a well-controlled quantum system, such as a quantum computer, we may solve quantum many-body problems with a cost polynomial of the number of particles. In recent years, to use a noisy quantum computer for quantum many-body problems, the variational quantum eigensolver (VQE) [1] has attracted much interest. In the VQE approach, a quantum many-body state is represented as a quantum circuit, and we optimize circuit parameters to minimize the energy expectation value. However, it is still unclear whether the VQE approach has an advantage over classical computation on practical quantum many-body problems.

In this talk, We will discuss the possibility of using tensor network representations of quantum many-body states to design an efficient quantum circuit suitable for near-future noisy quantum computers. As a concrete example, we will consider the spin liquid state in the honeycomb lattice Kitaev model [2]. For this model, a simple tensor network state can capture the qualitative properties of the spin liquid. By adding short-range excitations, we can also systematically improve its energy expectation value [3]. We will show that a similar procedure can be applied to the VQE approach by representing tensor network states as quantum circuits. We will discuss that we can efficiently optimize the infinite system by solving an optimization problem in small clusters through this approach.

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[2] A. Kitaev, Ann. Phys. 321, 2 (2006).
[3] H.-Y. Lee, R. Kaneko, T. Okubo, and N. Kawashima, Phys. Rev. Lett. 123, 087203 (2019).

Simulating the time evolution of isolated quantum many-body systems using infinite projected entangled pair states

Ryui Kaneko

The time evolution of isolated quantum many-body systems has been extensively investigated using analog quantum simulators, such as ultracold atoms in optical lattices and Rydberg atom arrays. In the development of these simulators, it is crucial to compare experimental results with quantitative numerical simulations performed on classical computers. However, simulating dynamics in 2D systems is more challenging compared to 1D and 3D systems. In this study, we demonstrate the effectiveness of the 2D tensor-network method based on infinite projected entangled pair states (iPEPS) for this purpose. Motivated by recent experiments conducted on Bose-Hubbard simulators, we specifically focus on the 2D Bose-Hubbard model as an example. Using the iPEPS method, we simulate the time evolution following a sudden quench starting from the Mott insulating phase. Our results show that the obtained single-particle correlation functions accurately reproduce the experimental findings. Additionally, we successfully extract the phase and group velocities from the correlation functions in a parameter region that has not been explored in experiments. Furthermore, we investigate the applicability of the iPEPS method to the 2D transverse-field Ising model, which holds potential for future analog quantum simulations utilizing Rydberg atom arrays.

Tensor-Ring Decomposition

Naoki Kawashima

It is useful to deform a given tensor into a ring of smaller tensors. Since it often provides us with compressed form of the data, it is applied in image compression and categorization, for example. If we can find a general way of finding the optimal or nearly optimal ring decompositions, we can use it in reducing the redundant internal correlation of a given tensor ring, which we typically encounter as a results of renormalization group transformations of physical models with tensor network representation. I review a few previous attempts at ring decompositions. Then, I discuss how we can apply techniques developed in information science to statistical mechanical models.

Generating function for projected entangled-pair state

Wei-Lin Tu

The tensor network algorithm has become one of the efficient numerical tools in studying the many-body systems. However, in obtaining the physical observables or related properties, often we need to consider the summation of a series of tensor graphs, resulting in the growth of the computational cost. Here, we introduce the usage of generating functions for tensor-network summation. By constructing the corresponding mother tensor networks of generating functions, we then take the gradient with respect to the target parameter, and the tensor summations can be directly evaluated. Previously we have shown that such measure can help obtain a well approximated low-energy excited state in the form of the Bloch state in one dimension, providing accurate simulation results [1]. In this presentation, we extend this idea to two dimensions for the infinite projected entangled-pair states (iPEPS) and will present some numerical results.

[1] Wei-Lin Tu, Huan-Kuang Wu, Norbert Schuch, Naoki Kawashima, and Ji-Yao Chen "Generating function for tensor network diagrammatic summation", Physical Review B 103, 205155 (2021).

Controlled bond expansion: a rank-adaptive approach for single-site DMRG and TDVP

Jheng-Wei Li

Traditional single-site density matrix renormalization group (DMRG) does not allow bond expansion; multi-site DMRG does but at much higher computational costs. For matrix product states (MPS), we present a controlled bond expansion (CBE) algorithm that yields two-site accuracy at single-site costs. Given an MPS, $¥Psi$, with a confined variational space, CBE explores its orthogonal subspaces and finds components carrying significant weight in $H ¥Psi$ to enrich it. This CBE approach in contrast with the previous perturbative expansion approaches is fully variational. Moreover, to simulate quantum dynamics using the time-dependent variational principle (TDVP), the same strategy applies. CBE alleviates the numerical difficulties of the standard, fixed-rank one-site TDVP integrator, and thereby greatly extends the time window over which time evolution can be simulated accurately and reliably.

The implementation of CBE--DMRG/TDVP does not require a high degree of technical sophistication. Hence, existing, optimized MPS codes can be easily adapted. We will illustrate the performance of CBE with several numerical examples on finite quantum lattices which carry interesting physics.

Variational Tensor Network Operator

Ying-Jer Kao

We propose a simple and generic construction of the variational tensor network operators to study the quantum spin systems by the synergy of ideas from the imaginary-time evolution and the variational optimization of trial wave functions. By applying these operators to simple initial states, accurate variational ground-state wave functions with extremely few parameters can be obtained. Furthermore, the framework can be applied to spontaneously study symmetry-breaking, symmetry-protected topological, and intrinsic topologically ordered phases, and we show that symmetries of the local tensors associated with these phases can emerge directly after the optimization without any gauge fixing. This provides a universal way to identify quantum phase transitions without prior knowledge of the system.

Accessing excited eigenstates of two-dimensional systems with isometric tensor network states

ShengHsuan Lin

t has been shown in previous works that the density matrix renormalization group (DMRG) can access highly-excited eigenstates of strongly disordered systems [1] and the low-lying excitation spectrum of critical systems [2] in 1D. We discuss the generalization of these approaches to 2D using the recently introduced DMRG¥textsuperscript{2} algorithm with 2D isometric tensor network states [3,4].

[1] Vedika Khemani, Frank Pollmann, S. L. Sondhi. Phys. Rev. Lett. 116, 247204 (2016)
[2] Natalia Chepiga and Frédéric Mila, Phys. Rev. B 96, 054425, (2017)
[3] Michael P. Zaletel and Frank Pollmann, Phys. Rev. Lett. 124, 037201, (2020)
[4] Sheng-Hsuan Lin, Michael P. Zaletel, and Frank Pollmann, Phys. Rev. B 106, 245102, (2022)

Rank-2 Toric Code

Yun-Tak Oh

TBD

Scale and conformal invariance in the long-range antiferromagnetic Ising chain: a VMC+RBM approach

Dong-Hee Kim

Scale invariance at criticality in many two-dimensional classical spin models imposes conformal symmetry that fixes the universality classes of critical exponents and restricts the form of correlation functions. While the transverse-field quantum Ising chain with short-range (SR) interactions inherits the 2D Ising universality class through the quantum-classical correspondence, a question has been raised for algebraically decaying long-range (LR) interactions, particularly in the antiferromagnetic side, below what value of the LR decay exponent the conformal symmetry breaks down. In this talk, we address this question by using a variational Monte Carlo method based on a neural-network quantum state ansatz implemented with the restricted Boltzmann machine. Performing finite-size-scaling analysis on the order parameter and susceptibility, we observe that the associated critical exponents agree well with the Ising class for all LR exponents examined. On the other hand, while the central charge extracted from the second Rényi entropy and the scaling dimension of the spin correlation function exhibit only weak deviation from the Ising values for a small LR exponent, the functional form of the correlation function under periodic boundary conditions indicates more explicit evidence of the conformal symmetry breakdown. It turns out that the correlation function deviates from the conformal field theory (CFT) prediction for the LR exponent roughly less than 2, corroborating the scenario proposed in the LR Kitaev chain where the CFT description can break down with the LR interactions while critical exponents being unchanged from the SR class.

Markov-Chain Monte Carlo in Tensor-Network Representation

Synge Todo

The partition functions of various classical and quantum lattice models can be represented as tensor networks. However, the exact contraction of a tensor network is generally exponentially expensive, and some approximation, such as low-rank approximation based on singular value decomposition, is usually required. Recently, we proposed a new tensor contraction method based on Monte Carlo sampling. The proposed method combines the stochastic basis transformation of tensors with the Markov chain Monte Carlo framework. It can entirely remove the systematic error due to a finite bond dimension of the low-rank approximation while keeping the high accuracy of the tensor-network method. We also demonstrate how the proposed method works for systems with negative (or complex) weights, where the standard Markov chain Monte Carlo suffers from a severe sign problem.

Klein bottle partition function and tensor networks

Hong-Hao Tu

In this talk, I will discuss how to combine the Klein bottle partition function and tensor networks to characterize 2D conformal critical theories and their adjacent phases. When the system is at a conformal critical point, the Klein bottle partition function exhibits a universal entropy (called "Klein bottle entropy") which is useful for characterizing the critical theory in lattice models. When the system is perturbed away from a conformal critical point by a relevant operator, the Klein bottle entropy is shown to be a universal scaling function which can be used to determine the scaling dimension of the perturbation operator via data collapse. I will also discuss how to use these results in tensor network numerics and present several benchmark examples.