Perspective on Time, Uncertainty and Quantum Computation

Abstracts (Alphabetical Order)

Ashhab, Sahel

Title: Time-Optimal Control of Quantum Operations for Quantum Computing

Abstract: Any quantum operation requires a minimum amount of time that depends on the Hamiltonian that describes the dynamics of the physical system. In particular, when we consider a controlled-dynamics scenario, where the Hamiltonian contains freely adjustable control functions, optimal-control-theory (OCT) techniques have been developed to find the optimal functions that maximize the fidelity of the performed operation with the desired (target) operation. In other words, these techniques allow us to find control functions that bring the physically performed operation as close as possible to the target operation. These techniques can readily be adapted to find the minimum time needed to perform any given target operation. We used OCT techniques to find the minimum times needed to perform a variety of multi-qubit and multi-qudit operations. Our results can serve as benchmarks for the speed of current state-of-the-art operations on quantum computers.

Braak, Daniel

Title: A Classification Scheme for Continuous Spectra

Abstract: Hilbert spaces of entire functions have proven useful to obtain the spectral determinants associated with the point spectrum of some physically relevant self-adjoint operators. It will be shown that they also yield detailed information about the asymptotic expansions of formal solutions to the eigenvalue problem which leads to a classification of all possible spectral measures belonging to the absolutely continuous spectrum.

Bustos, Cid Reyes

Title: Heat Kernel and Time Evolution for Quantum Rabi Models

Abstract: In this talk we review the computation of the heat kernel for the quantum Rabi model, one of the fundamental models from light-matter interactions, based on the Kato-Trotter product formula. From the heat kernel formula, the time propagator may be obtained by analytic continuation. The exact formula for the heat kernel allows us to give precise estimations and bounds for applications including spectral zeta function. In addition, we give some comments and partial results of the method for certain generalizations of the quantum Rabi model.

Coppo, Alessandro

Title: Quantum and Classical Dynamics from Entanglement with a Glimpse near Black Holes

Abstract: In this talk, I present a picture of physical systems where time emerges as a manifestation of quantum entanglement with a clock, regardless of whether the system evolution is classical or quantum. The setting is based on the Page and Wootters mechanism, combined with tools from Large-N quantum approaches given in terms of generalized coherent states. We investigate how quantum dynamics transforms into a classical-like behaviour when macroscopicity conditions are met by the clock alone, or by the clock and the evolving system altogether. Within this framework, we derive the customary energy–time uncertainty relation, as well the familiar Schrödinger and Hamilton equations of motion as imprints of quantum correlations with the clock. The classical notion of time, together with that of phase-space and trajectories on it, find their place. Starting from the insight that a clock capability to capture the full dynamics of a system diminishes as its energy scale decreases, we finally explore a novel intriguing possibility: could black holes serve as fundamental timekeepers in the universe, exploiting quantum entanglement to function as clocks for nearby test particles?

Emori, Haruki

Title: Falsifiable Quantum Simulation: Experimental Probes of Error–Disturbance Relation, OTOC, and Arai–Miyamoto Inequality Using Quantum Computers

Abstract: Quantum computers offer significant potential as "falsifiable quantum simulators," providing a valuable application even before the advent of fault-tolerant quantum computing (FTQC). In the current early-FTQC era, quantum computers can be leveraged to experimentally test the foundational principles of quantum mechanics. In this presentation, I will introduce our work demonstrating this approach. I will discuss three core topics: First, the experimental verification of the uncertainty principle for error and disturbance. Second, the measurement of the Out-of-Time-Ordered Correlator (OTOC), a key indicator of quantum chaos. Finally, I will present our ongoing efforts toward the experimental validation of the Arai-Miyamoto inequality. These studies highlight the capability of near-term quantum computers to serve as powerful platforms for probing complex quantum phenomena.

Galapon, Eric A.

Title: Temporal and Non-Temporal Observables: A Framework Emerging from Quantum Time of Arrival Operators

Abstract: Our investigations on quantum time of arrival (TOA) operators reveal that the spectral properties of a time operator can acquire an unambiguous physical interpretation independent of the postulates of standard quantum measurement theory. These spectral properties can be dynamically interpreted—the eigenfunctions of quantum TOA operators evolve unitarily

to arrive at a specific spatial point at their respective eigenvalues. This result suggests the need for a modification of the standard quantum measurement theory, which currently admits no exception in interpreting the spectra of observables. We foresee that the modified theory will require a classification of quantum observables into two categories—temporal and non-temporal observables—the latter belonging to a generalized framework that accommodates time as a dynamical observable. Temporal observables are conjectured to correspond to the Hilbert-space solutions of the time–energy canonical commutation relation for a given Hamiltonian. Most remarkably, the theory of TOA operators establishes a link between the quantum time of arrival problem and the problem of the appearance of particles in quantum mechanics. Whereas in the standard formulation, particle appearance arises from wave-function collapse induced by position measurement, the dynamics of confined TOA operators suggest a two-step process: an initial collapse into one of the TOA eigenfunctions, followed by the unitary Schrödinger evolution of that eigenfunction. This implies that particle appearance—at least within the TOA framework—originates not from position measurements but from time of arrival measurements, and that the conventional notion of wave-function collapse is not fundamental but decomposable into causally separated processes. These results invite a reconsideration of the foundations of quantum measurement theory.

Gea-Banacloche, Julio

Title: Quantum Measurement and Irreversibility

Abstract: In a projective measurement, information on the pre-measurement state of a system is irretrievably lost; hence, a consistent description of such measurements appears to be impossible in the time-reversible framework of the Schrödinger equation for closed systems. However, the standard formalism of quantum mechanics has been used successfully to describe many irreversible processes, such as spontaneous emission. This strongly suggests that the "measurement problem" resides not in the formalism itself, but in its interpretation. Here I will introduce three basic interpretational principles and show that, when properly applied, they allow for a consistent description of a real-world projective measurement. Interestingly, in this example, the "macroscopic nature of the measurement apparatus" plays no role in the (presumed) objective state reduction; rather, the latter may be said to be due only to irreversibility at the microscopic level.

Hasegawa, Yuji

Title: Fundamental Phenomena in Quantum Mechanics Studied with Neutrons

Abstract: The validity of quantum-mechanical predictions has been confirmed with a high degree of accuracy in a wide range of experiments. Although the statistics of the outcomes of a measuring apparatus have been studied intensively, little has been explored and is known regarding the accessibility of quantum dynamics. For this sort of fundamental studies of quantum mechanics, interferometric approaches, in particular by the use of neutron's matter-waves, provide almost ideal experimental circumstances. This device explicitly exhibits quantum interference between spatially separated beams in a macroscopic scale. Using this instrument,

alternative theories of quantum mechanics, Kochen-Specker theorem and so on have been investigated. Recently, as a study of quantum dynamics, neutron interferometer experiments are carried out: a new counter-intuitive phenomenon, called quantum Cheshire-cat, is observed. In this experiment, separation of the neutron and its property, i.e., spin, was confirmed. Further investigations demonstrate the separation even with the delayed-choice circumstances and the separation of the neutron, spin, and energy in a three-path setup. In my talk, I am going to give an overview and present actual consequences of neutron optical experiments to investigations of fundamental aspect of quantum mechanics.

Hiroshima, Fumio

Title: Time Operators Associated with Quantum Harmonic Oscillators

Abstract: Conjugate operator T of the one-dimensional harmonic oscillator N is defined as an operator satisfying the canonical commutation relation $[N, T] = -i$ on some domain, which is not necessarily dense. Let $\mathcal{T}$ be the set of conjugate operators of N. In this talk a classification of this set is given and parametrized by pairs (ω, m). Moreover, the time evolution

$$T_{\omega,m}(t) = e^{itN} T_{\omega,m} e^{-itN}$$

is investigated, and it is shown that $T_{\omega,m}(t)$ is periodic. [https://arxiv.org/abs/2404.12286]

Ikeda, Tatsuhiko

Title: From Floquet Hamiltonians to Quantum Simulation: Exploring the Time Structure of Driven Systems

Abstract: Periodic driving provides a unique platform to explore the interplay between time evolution, thermalization, and effective Hamiltonians in quantum many-body systems. In this talk, I will review the theoretical framework of Floquet systems, emphasizing the unboundedness and branch structure of the Floquet Hamiltonian and its implications for thermalization and prethermal regimes. I will then discuss recent results on Floquet ground states and prethermal stability, as well as connections between Floquet theory and Trotterized time evolution relevant to NISQ-era quantum simulations. These studies reveal that discrete or periodic time evolution naturally leads to effective modular structures reminiscent of a "time operator" conjugate to the Floquet Hamiltonian. I will close by discussing possible directions where such a perspective may bridge Floquet engineering, quantum measurement theory, and the foundational problem of time in quantum mechanics.

Itou, Etsuko

Title: New Developments in Theoretical Particle Physics: Toward Quantum Computation

Abstract: In this talk, I will introduce several recent developments related to classical and quantum algorithms based on the Hamiltonian formulation of quantum field theory. In particle physics, large-scale numerical simulations using supercomputers have long been employed to

make theoretical predictions of physical phenomena. These studies are typically based on lattice gauge theories in the Lagrangian formalism and evaluated through Monte Carlo methods. However, such approaches face severe limitations due to the well-known sign problem. With the emergence of quantum computers, the Hamiltonian formulation of field theory has gained renewed attention as a framework more suitable for quantum computation. Approaches such as tensor network methods and quantum algorithms are now being actively explored. I will discuss what kinds of problems are of current interest in this field, how far recent research has progressed, and what prospects lie ahead for the future of particle physics in the era of quantum computation.

Kuramochi, Yui

Title: Wigner–Araki–Yanase Theorem for Quantum Measurements with Unbounded Conserved Observables

Abstract: It is one of the fundamental questions of quantum information science that what kind of quantum operations are permitted by nature. One important example of this kind of restriction on implementability of operations is the Wigner-Araki-Yanase (WAY) theorem, which states that any observable that does not commute with the conserved quantity of the system cannot be measured without error. In this talk, starting from basic notions of quantum measurement theory, we introduce the WAY theorem, especially the recent proof of the WAY theorem for unbounded conserved observables and the WAY-type theorem for unitary operations based on the paper [YK, H. Tajima, Phys. Rev. Lett. 131, 210201].

Maccone, Lorenzo

Title: Geometric Event-Based Relativistic Quantum Mechanics

Abstract: We propose a special relativistic framework for quantum mechanics. It is based on introducing a Hilbert space for events. Events are taken as primitive notions (as customary in relativity), whereas quantum systems (e.g. fields and particles) are emergent in the form of joint probability amplitudes for position and time of events. Textbook relativistic quantum mechanics and quantum field theory can be recovered by dividing the event Hilbert spaces into space and time (a foliation) and then conditioning the event states onto the time part. Our theory satisfies the full Lorentz symmetry as a 'geometric' unitary transformation, and possesses relativistic observables for space (location of an event) and time (position in time of an event).
Based on [New J. Phys. 25 (2023) 023027], `https://doi.org/10.1088/1367-2630/acb793`

Nakatsugawa, Keiji

Title: Caldeira–Leggett Quantum Time Crystals

Abstract: We have shown that quantum time crystals can be realized using decoherence [1] and that their dynamics can be formulated in terms of time operators [2]. In our recent work, we extend these ideas and propose the Caldeira–Leggett quantum time crystal, where the interaction of a quantum system with a sub-Ohmic environment leads to periodic revivals

of quantum coherence [3]. By extending the Caldeira–Leggett model of quantum Brownian motion to sub-Ohmic spectral densities, we derive explicit conditions on the environmental memory kernel under which time-translation symmetry is broken and long-time coherent revivals emerge. In this talk, we will review the time-operator formulation of time-crystal dynamics and explain how the Caldeira–Leggett model provides a solvable framework that links time operators, decoherence, and open-system dynamics.

[1] KN, T. Fujii, and S. Tanda, Phys. Rev. B 96, 094308 (2017).
[2] KN, T Fujii, A Saxena and S Tanda, J. Phys. A 53, (2020).
[3] KN, S. Tanda, and T. Fujii, Phys. Rev. A 112, 022202 (2025).

Nguyen, Son, Thi Kim

Title: Fuzzy-Fractional Semigroup Frameworks for Uncertainty Modeling in Schrödinger-Type Evolution

Abstract: This talk presents an analytic approach to modeling uncertainty in evolution systems through a semigroup framework extended in two directions: fractional dynamics and fuzzy/interval representations. Our focus is on developing abstract operator structures and fractional analytic tools for evolution equations influenced by uncertain data and parameters, thereby enabling a systematic examination of how noise, imprecision, and measurement-related variability affect the system's dynamics. Fractional derivatives are employed to capture non-Markovian behavior and long-memory effects, while fuzzy - interval modeling provides a coherent means of representing structured forms of uncertainty. Within this framework, Schrödinger-type dynamics are viewed as a representative instance of evolution processes subjected to such uncertainty.

Ozawa, Masanao

Title: Time in a Macroscopic Extension of the Quantum Harmonic Oscillator

Abstract: The Hermitian time operator does not exist on the Hilbert space of quantum states, but the optimum POVM may exist that describes the optimal measurement of time. By the Naimark theorem, this POVM can be extended to a projection-valued measure representing a Hermitian operator on a larger Hilbert space. We consider the physical meaning of the extended Hilbert space and the dilated Hermitian operator. In this talk, we study the phase of a harmonic oscillator as time in quantum mechanics. We show that the extended Hilbert space represents classical mechanics and that the optimum time POVM extends to a classical time observable by constructing a Naimark dilation of the optimal POVM by adding quantum states with infinite excitations to the original Hilbert space by a mathematically rigorous way based on non-standard analysis, so that we obtain a Hermitian operator on the extended Hilbert space. We show that this Hilbert space represents classical mechanics and the dilation of the phase POVM coincide with the classical time operator. Thus, the optimal time POVM is the projection of the classical time operator onto the subspace generated by states with finite excitations.

Richard, Serge

Title: Time Delay for One-Dimensional Anisotropic Quantum Walks

Abstract: During this presentation, we shall firstly recall the general framework of time delay, defined in terms of sojourn time, as developed abstractly for the self-adjoint setting and for the unitary setting. Sufficient conditions are then exhibited for its existence and for its equality with the Eisenbud-Wigner time delay. This abstract theory is then applied to 1-dimensional quantum walks with two different asymptotic coin operators. This talk is based on an on-going joint project with Rafael Tiedra de Aldecoa.

Sasaki, Itaru

Title: TBA

Abstract: TBA

Suzuki, Akito

Title: Weak Limit Theorem for 2D Quantum Walks: Seeking Genuine 2D Konno Distribution

Abstract: The Weak Limit Theorem (WLT) for quantum walks (QWs) is the quantum analog of the Central Limit Theorem. While the 1D case (Konno distribution) was established two decades ago, its generalization to higher dimensions has remained a significant challenge. This talk presents an exact analytical representation of the limiting probability density function (PDF) for a general class of 2D two-state QWs. A key test for a "genuine" 2D generalization is its 1D limit. Previous explicit 2D PDFs fail this test; they degenerate to trivial ballistic motion, not the non-trivial 1D Konno distribution. We derive "2D Konno functions" that resolve this discrepancy. We demonstrate these are the true generalization by proving they properly converge to the established 1D Konno distribution in the appropriate limit.

Tajima, Hiroyasu

Title: Universal Tradeoff Relations between Resource Cost and Irreversibility of Channels: General-Resource Wigner-Araki-Yanase Theorem and Beyond

Abstract: Quantum technologies offer exceptional – sometimes almost magical – speed and performance, yet every quantum process costs physical resources. Designing next-generation quantum devices, therefore, depends on solving the following question: which resources, and in what amount, are required to implement a desired quantum process? Casting the problem in the language of quantum resource theories, we prove a universal cost-irreversibility tradeoff: the lower the irreversibility of a quantum process, the greater the required resource cost for its realization. The trade-off law holds for a broad range of resources – energy, magic, asymmetry, coherence, athermality, and others – yielding lower bounds on resource cost of any quantum channel. Its broad scope positions this result as a foundation for deriving the following key results: (1) we show a universal relation between the energetic cost and the irreversibility for

arbitrary channels, encompassing the energy-error tradeoff for any measurement or unitary gate; (2) we extend the energy-error tradeoff to free energy and work costs; (3) we extend the Wigner-Araki-Yanase theorem, which is the universal limitation on measurements under conservation laws, to a wide class of resource theories: the probability of failure in distinguishing resourceful states via a measurement is inversely proportional to its resource cost; (4) we prove that infinitely many resource-non-increasing operations in fact require an infinite implementation cost. These findings reveal a universal relationship between quantumness and irreversibility, providing a first step toward a general theory that explains when – and how – quantumness can suppress irreversibility.

Tanda, Satoshi

Title: TBA

Abstract: TBA

Yamamoto, Kazuhiro

Title: Is Gravity Quantum? — From Thought Experiment to Optomechanical Test

Abstract: The crossover between the world of gravity and the world of quantum mechanics is one of the greatest unsolved problems in modern physics. Against the backdrop of advances in quantum technology and quantum information science, this talk introduces research that explores the quantum nature of gravity– namely, whether gravity obeys the laws of quantum mechanics. In the first part, I will focus on a paradox arising from a thought experiment and discuss the theoretical aspects of quantum entanglement generated by gravity. In the second part, I will discuss the experimental feasibility of testing gravity-induced entanglement using optomechanical systems.

Yoshino, Saori

Title: Limit Theorem for an Interpolating Walk between Random Walks and Quantum Walks on the One-Dimensional Lattice

Abstract: It is known that quantum walks and random walks exhibit different characteristics in terms of their probability measures and variances. We propose a model that interpolates between quantum walks and persistent (correlated) random walks using one parameter on the one-dimensional lattice. As a result of the analysis based on Kato's perturbation theory, it was found that the limit behavior of our walk model on the one-dimensional lattice is characterized by the normal variance mixture with the arcsine law. As a future direction, we plan to construct interpolating models not only on the one-dimensional lattice but also on more general graphs, and to analyze the limit distribution in such models.