Abstract

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Title: Robust Quantum Metrology under the Effect of Dephasing

Abstract: Quantum metrology is a field whose aim is to improve the sensitivity of the sensor by using quantum properties such as a superposition or an entanglement. However, a quantum state is usually fragile against noise, and so it is not straightforward to construct a robust quantum sensor with realistic conditions that typically assume an unwanted coupling with the environment. Here, we propose a novel quantum sensor that estimates the amplitude of target fields with the sensitivity beyond the classical limit under the effect of the dephasing. More specifically, for a measurement time T, the uncertainty of the estimation of the target fields scales as T^{-1} by using our proposed quantum sensor with dephasing while the uncertainty scales as $T^{-0.5}$ for any classical sensors. The key idea in our scheme is a frequent implementation of quantum teleportation that can suppress dephasing while the information from the target fields keeps growing. Our method has the potential to realize a quantum sensor with a sensitivity far beyond that of any classical sensor.

[ref] Yuichiro Matsuzaki, and *et al*, Phys. Rev. Lett. 120, 140501 (2018)

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Title: Hilbert space structure induced by quantum probes

Abstract: In a general setting of quantum control, it is unrealistic to control all of the degrees of freedom of a quantum system. We consider a scenario where our direct access is restricted to a small subsystem S that is constantly interacting with the rest of the system E. What we investigate here is the fundamental structure of the Hilbert space that is caused solely by the restrictedness of the direct control. We clarify the intrinsic space structure of the entire system and that of the operations which could be activated through S. One significant finding is that there is a sharp distinction between the cases of $\dim \mathcal{H}_S \geq 3$ and $\dim \mathcal{H}_S = 2$ in terms of the nature of possible operations in E. Also, although the controllability may be expanded by appending an extra dimension(s) to two-dimensional S, once $\dim \mathcal{H}_S$ exceeds 3 no further algebraic expansion occurs by further enlargement of S. These can be deduced by considering the algebraic structure, which is the *Jordan algebra* formed with hermitian operators, naturally induced by the setting of limited access. Since our analysis is totally free from specific properties of any physical systems, it would form a solid basis for obtaining deeper insights into quantum control related issues, such as controllability and observability.

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Title: A look at adversarial quantum learning: quantum computation, security and machine learning

Abstract: The success of the modern internet relies in no small part on understanding the interplay between computation and security. More recently this area has also seen contributions from machine learning, including spam filters and malware detection. With the rising prevalence of machine learning algorithms, it is also important to address whether new security issues arise. Machine learning applications often require training or test data that originate from remote data centres or sensors. This decentralised set-up opens the door to adversaries that could exploit existing vulnerabilities in those algorithms. Evidence suggests that these vulnerabilities can grow with the dimensionality of the data. As quantum technologies become more accessible, these same concerns for quantum data is expected to become more important in a future quantum internet, especially as the most classically-intractable quantum systems of interest are usually high-dimensional. In this area which we can call adversarial quantum learning, we ask some basic first questions: How do we verify high-dimensional quantum data with less resources? How do errors or adversarial changes in quantum data affect the probability of misclassification? Is there a dependence on dimensionality? How do we detect unusual quantum data? We take some first steps in addressing these questions and look towards the future of computation and security on quantum data.

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Title: Quantum Information Geometry of a Qubit System: Parameter Estimation View

Abstract: A set of probability distributions (measures) can be regarded as a statistical manifold equipped with the Fisher metric and dual affine connections. Information geometry is a power tool to study differential geometrical aspect of statistical inference problems. Classical information geometry is well established and the state space is dually flat with respect to the dual connections. When we study a set of density matrices as a quantum statistical manifold, the geometrical structure is completely different from the classical case. First, there is no unique invariant metric. Second, the state space is not dually flat in general and non-vanishing torsion plays an important role. In this talk, we first give a short review on classical information geometry and then show how it can be generalized to the quantum case in view of parameter estimation problems. We mostly work on the simplest quantum system, a qubit system, to confirm that even such a simple quantum system can exhibit a non-trivial geometrical structure.

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Title: A C*-algebraic approach to quantum measurement

Abstract: We propose a new framework for quantum measurement theory in the C*-algebraic setting. In C*-algebraic quantum theory, we encounter the existence of unitarily inequivalent *-representations of C*-algebras. It is, however, known that this is nothing but the existence of different sectors which distinguish macroscopic classical levels of quantum systems. Therefore, we have to describe processes of measurements consistent with transitions among sectors. Processes of measurements in the Schrödinger picture are examined herein. We analyze completely positive instrument defined on C*-algebras and their representation theorem.

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Title: Higher-order quantum operations on unitary operations with multiple calls

Abstract: Quantum computers are not merely a device to process information but also serve as a tool to manipulate quantum systems, including their dynamics. The dynamics of quantum systems is described by quantum maps. Thus the idea of manipulating quantum dynamics necessarily leads to understanding a higher level of transformations, whose mathematical representation becomes a "supermap", a map between maps. In this talk, we discuss some of our recent work on the properties of "supermaps" and their corresponding "higher-order quantum operations", i.e., their implementations within the conventional quantum circuit model. The input quantum operations are modeled as an oracle circuit. In particular, we consider higher-order quantum operations whose input quantum operations are restricted to unitary operations and that make multiple calls of the input unitary operations.

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Title: Efficient evaluation of quantum topological stabilizer codes

Abstract: In order to build a scalable quantum computer, we need to decrease an effective error probability of qubits to a sufficiently small value. Quantum error correction (QEC) is a vital technology to achieve this. With QEC, we can construct clean logical qubits from several noisy physical qubits. According to the theory of QEC, we can decrease an effective error probability of logical qubits to an arbitrary small value by increasing the number of physical qubits if an error probability of physical qubits is smaller than a value called threshold. Therefore, physical qubits with a small error probability have been developed experimentally, and a method for realizing QEC with a large threshold value has been studied theoretically. One of the most essential progresses in theoretical QEC is the discovery of topological stabilizer codes. Topological stabilizer codes are a family of QEC codes and have several preferable properties for realizing QEC such as high threshold values. On the other hand, we encounter several problems when we try to experimentally perform QEC with topological stabilizer codes. In this talk, we focus on two essential problems among them. First, it is hard to efficiently evaluate threshold values of topological stabilizer codes under a practical noise model, since it requires direct simulation of noisy quantum circuits in general. Furthermore, since the optimal decoding of topological stabilizer codes is believed to be computationally hard, the time for performing the optimal decoding grows exponentially to the number of physical qubits. Here, we propose practical solutions to each problem. For the first problem, we show that threshold values under some practical noise models can be efficiently calculated with the simulation based on fermionic Gaussian dynamics, and we also show that threshold values are decreased if noise becomes coherent. For the latter problem, we show a general framework to utilize machine learning for fast and near-optimal decoding, and numerically show that the performance of machine-learning-based decoders can be improved with some criteria.

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Title: Complex spherical s-distance $\mathcal{T}$-designs

Abstract: A finite subset X on the unit complex sphere $\Omega(d) \subset \mathbb{C}^d$ is called a complex spherical $\mathcal{T}$-design if

$$\frac{1}{|\Omega(d)|}\int_{\Omega(d)} f(\boldsymbol{z})\mathrm{d}\boldsymbol{z} = \frac{1}{|X|}\sum_{\boldsymbol{z}\in X} f(\boldsymbol{z})$$

holds for all $f(\boldsymbol{z}) \in \mathrm{Hom}(k,\ell)$ with $(k,\ell) \in \mathcal{T}(\subset \mathbb{N}^2)$. Here $\mathrm{Hom}(k,\ell)$ is the subspace of polynomials which are homogeneous of degree k in variables $\{z_1,\ldots,z_d\}$ and homogeneous of degree ℓ in $\{\overline{z_1},\ldots,\overline{z_d}\}$. The set X is an s-distance set if $|A(X)| = s$, where $A(X) = \{\langle \boldsymbol{y},\boldsymbol{z}\rangle \mid \boldsymbol{y},\boldsymbol{z} \in X, \boldsymbol{y} \neq \boldsymbol{z}\}$.

We are interested in the classicication of *tight* complex $\mathcal{T}$-designs including $\mathcal{T}_t^{(1)} = \{(k,\ell) \mid 0 \le k,\ell \le t\}$, $\mathcal{T}_t^{(2)} = \{(k,\ell) \mid 0 \le k+\ell \le t\}$ as well as $\mathcal{T}_t^{(3)} = \{(t,t)\}$. In this talk, we will focus on complex 4-distance $\mathcal{T}_2^{(1)}$-designs and discuss the relation between these designs and SIC-POVMs.

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Title: Optimal shortcuts to adiabaticity for spin dynamics

Abstract: Rapid preparation, manipulation, and correction of spin states with high fidelity are requisite for quantum information processing and quantum computating. In this paper, we propose a fast and robust approach for controlling two spins with Heisenberg and Ising interactions. By using the concept of shortcuts to adiabaticity, we first design inversely the driving magnetic fields for achieving fast spin flip or generating the entangled Bell state, and further optimize them with respect to the error and fluctuation. In particular, the designed shortcut protocols can suppress efficiently the unwanted transition or control error induced by anisotropic antisymmetric Dzyaloshinskii-Moriya exchange. Several examples and comparisons are illustrated, showing the advantages of our developed methods. Finally, we emphasize that the results can be naturally extended to multiple interacting spins and other quantum systems in an analogous fashion.

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Title: State-dependent approach to quantum measurements and universally valid uncertainty relations

Abstract: Quantum measurement theory was instituted by founders of quantum mechanics around 1932, but was restricted to repeatable or approximately repeatable measurements (cf. Schrödinger [1, p. 329], Dirac [2, p. 36], and von Neumann [3, p. 335]). A completely general theory of measurement in quantum mechanics was established in 1984 [4] in the framework of the Davies-Lewis theory of quantum instruments [5]. According to this modern quantum measurement theory, a measurement of an observable has been treated only state-independently from its inception; namely, a measurement with the POVM Π is an accurate measurement of an observables A if Π is the spectral measure of the observable A [4]. However, recent attempts to reformulate Heisenberg's uncertainty principle [6] to be universally valid for every measurement has made evident the demand for thorough understanding of measurements of observables in a state-dependent formulation. Here, we discuss the following topics recently published for this purpose: universally valid uncertainty relations [7, 8, 9, 10, 11], quantum perfect correlations [12, 13], state-dependent simultaneous measurability [14, 15, 16], soundness and completeness of quantum root mean square errors [17], experimental tests for universally valid uncertainty relations [18, 19, 20, 21, 22], Heisenberg's original derivation of the uncertainty relation [23], measurements and universally valid uncertainty relations in quantum field theory (cf. Okamaura's talk) [24, 25].

References

[1] E. Schrödinger, *Proc. Am. Philos. Soc.* **124**, 323 (1980). [Originally published: Die gegenwärtige Situation in der Quantenmechanik, *Naturwissenschaften* **23**, 807–812, 823–828, 844–849 (1935)].

[2] P. A. M. Dirac, *The Principles of Quantum Mechanics* (Oxford UP, Oxford, 1958), fourth edn.

[3] J. von Neumann, *Mathematical Foundations of Quantum Mechanics* (Princeton UP, Princeton, NJ, 1955). [Originally published: *Mathematische Grundlagen der Quantenmechanik* (Springer, Berlin, 1932)].

[4] M. Ozawa, *J. Math. Phys.* **25**, 79 (1984).

[5] E. B. Davies, J. T. Lewis, *Commun. Math. Phys.* **17**, 239 (1970).

[6] W. Heisenberg, *Z. Phys.* **43**, 172 (1927). [English translation by J. A. Wheeler and W. H. Zurek: The physical content of quantum kinematics and mechanics, in *Quan-*

tum Theory and Measurement, edited by J. A. Wheeler and W. H. Zurek (Princeton UP, Princeton, NJ, 1983), pp. 62–84].

[7] M. Ozawa, *Phys. Rev. A* **67**, 042105 (2003).

[8] M. Ozawa, *Int. J. Quant. Inf.* **1**, 569 (2003).

[9] M. Ozawa, *Ann. Physics* **311**, 350 (2004).

[10] M. Ozawa, Disproving Heisenberg's error-disturbance relation (2013). ArXiv:1308.3540v1 [quant-ph].

[11] M. Ozawa, Error-disturbance relations in mixed states (2014). ArXiv:1404.3388 [quant-ph].

[12] M. Ozawa, *Phys. Lett. A* **335**, 11 (2005).

[13] M. Ozawa, *Ann. Physics* **321**, 744 (2006).

[14] M. Ozawa, *Found. Phys.* **41**, 592 (2011).

[15] M. Ozawa, *AIP Conf. Proc.* **1363**, 53 (2011).

[16] M. Ozawa, *New Generat. Comput.* **34**, 125 (2016).

[17] M. Ozawa, Soundness and completeness of quantum root-mean-square errors (2018). ArXiv:1806.03780 [quant-ph].

[18] J. Erhart *et al.*, *Nat. Phys.* **8**, 185 (2012).

[19] S.-Y. Baek, F. Kaneda, M. Ozawa, K. Edamatsu, *Sci. Rep.* **3**, 2221 (2013).

[20] G. Sulyok *et al.*, *Phys. Rev. A* **88**, 022110 (2013).

[21] F. Kaneda, S.-Y. Baek, M. Ozawa, K. Edamatsu, *Phys. Rev. Lett.* **112**, 020402 (2014).

[22] B. Demirel, S. Sponar, G. Sulyok, M. Ozawa, Y. Hasegawa, *Phys. Rev. Lett.* **117**, 140402 (2016).

[23] M. Ozawa, *Curr. Sci.* **109**, 2006 (2015). ArXiv:1507.02010 [quant-ph].

[24] K. Okamura, M. Ozawa, *J. Math. Phys.* **57**, 015209 (2016).

[25] K. Okamura, M. Ozawa, Universally valid uncertainty relations in general quantum systems (2018). ArXiv:1808.10615 [quant-ph].

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Title: On the Entanglment Entropy of Massive Scalar in 2 dimension

Abstract: In quantum field theory(QFT), Entanglement Entropy (EE) or Rényi Entanglement Entropy (REE) is used as a measure of entanglement between two regions in the space. Here we want to consider the time evolution of (R)EE for scalar field theory. Acting with a spacetime local operator on the vacuum state can change the entanglement structure in the space, and so the (R)EE. It is known that in free scalar QFT case, the time evolution of (R)EE is the same as we consider a propagating particle with the speed of light. However, it is not clear yet if this property holds also for massive scalar QFT. In this talk, I want to discuss the case in 2-dimensional spacetime.

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Title: Far-from-equilibrium dynamics of the Bose-Hubbard model: Quantum and classical simulations

Abstract: Ultracold atoms in optical lattices have been successfully used as analog quantum simulators for Hubbard-type models. In particular, it has been established that they can exhibit better performance for non-equilibrium dynamics in generic systems than numerical simulations with classical computers. Nevertheless, since those quantum simulators are analog, comparison with theories is essential in order to make simulated results reliable. We will report recent development of ultracold-atom quantum simulators at Kyoto University especially from a theoretical viewpoint. Specifically, we focus on the Bose-Hubbard system, and discuss dynamics subjected to a sudden quench across the quantum phase transition from a Mott insulator to a superfluid. Using the truncated Wigner approximation and the matrix-product-state method, we numerically analyze the energy redistribution and the correlation propagation to present quantitative comparison with the results obtained by the quantum simulator.

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Title: Designing efficient processes with interacting systems

Abstract: Performing non-quasi-static processes on quantum systems can create large amounts of irreversibility if driven too quickly, which can have disastrous effects on quantum state engineering and thermodynamic engine cycles. One way to negate these effects is to use shortcuts to adiabaticity (STA) which would allow one to realize adiabatic dynamics in short finite times. Although well established for non-interacting and mean-field systems, difficulties arise when including realistic contact interactions in few and many-body systems. In the first part of my talk I will outline our method for inverse engineering STAs using a simple variational ansatz for interacting few body systems. Specifically our designed STA produces a fast ramping of strong interactions between different particles, thereby creating strong correlations which may be used to realize efficient collisional quantum gates. By looking beyond the usual fidelity of the final state, we characterize the efficiency of the STA through the thermodynamical properties of the system which provides more information about the amount of non-adiabatic energy present in the few-body state. In the second part of my talk we extend this STA to improve the efficiency of a strongly-interacting many-body heat engine about a quantum critical point. We show that designing the STA to minimize unwanted excitations of specific unstable subsystems one can significantly improve the operation of a finite time engine cycle. Finally, we show that the N-body interacting heat engine can outperform an equivalent ensemble of N non-interacting single particle heat engines, highlighting the many-body supremacy of the interacting system.

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Title: Quantum clock synchronization without synchronized clocks

Abstract: A major outstanding problem for many quantum clock synchronization protocols is the hidden assumption of a common phase reference between the parties to be synchronized. In general, the definition of the quantum states between two parties do not have consistent phase definitions, which can lead to an unknown systematic error. We show that despite prior arguments to the contrary, it is possible to remove this unknown phase via entanglement purification. This closes the loophole for entanglement based quantum clock synchronization protocols, which is a non-local approach to synchronize two clocks independent of the properties of the intervening medium. Starting with noisy Bell pairs, we show that the scheme produces a singlet state for any combination of (i) differing basis conventions for Alice and Bob; (ii) an overall time offset in the execution of the purification algorithm; and (iii) the presence of a noisy channel. Error estimates reveal that better performance than existing classical Einstein synchronization protocols should be achievable using current technology.

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Title: On upper bound for energy extraction via local operations

Abstract: A heat engine in the classical thermodynamics is a system to extract energy from a sufficiently large thermal bath. Recently, there are many studies that reconsider the heat engine in terms of the quantum mechanics. Information theoretical techniques are often utilized in these studies. In this talk, we consider a general version of the heat engine in the context of the quantum mechanics. This engine is defined as a system consisting of a small system and a large system interacting with each other. We assume that we can control only the small system and do not require that the large system is a thermal bath. We give an upper bound of the energy extraction by controlling the small system in this situation. Furthermore, we will discuss the efficiency and the realisability of this engine.

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Title: Single microwave-photon detector using dressed-state engineering

Abstract: Single-photon detection is a requisite technique in quantum-optics experiments in both the optical and the microwave domains. However, the energy of microwave quanta is four to five orders of magnitude less than their optical counterpart, making the efficient detection of single microwave photons extremely challenging. We demonstrate the detection of a single microwave photon propagating through a waveguide. The detector is implemented with an impedance-matched artificial Λ system comprising the dressed states of a driven superconducting qubit coupled to a microwave resonator. Each signal photon deterministically induces a Raman transition in the Λ system and excites the qubit. The subsequent dispersive readout of the qubit produces a discrete ‘click’. Recently, we also realize a real-time microwave photon detector using dressed-state engineering .

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Title: Theoretical study on fast coherent control of a circuit QED system

Abstract: We derive the pump field for fast population transfer in a qubit-resonator coupled system. Our numerical results show that the high fidelity population transfer can be realized even in the case where the Stokes field is not tunable. The efficiency of STIRAP is also examined. A possible application to single microwave photon source is discussed.