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KIAS 2018 Workshop on

Superconducting Quantum Information

Nov 18 (Sunday) - Nov 20 (Tuesday), 2018

KIAS, Seoul, Korea

[Rm 8101, Bldg 8]

Invited Speakers

Yasunobu NAKAMURA (Univ of Tokyo)

Rudy Raymond H. P. (IBM Research)

Yonuk CHONG (KRISS)

Joonsuk HUH (SKKU)

Dae-Hyun KIM (Kyungpook Ntnl U)

Mahn-Soo CHOI (Korea U)

Kyungsun MOON (Yonsei U)

Zidan WANG (U Hongkong)

Peter LEEK (U Oxford)

Jaewoo JOO (U Oxford)

Organizer

Jaewan KIM (KIAS), jaewan(a)kias.re.kr

Nov 18 (Sunday)

2:30 - 3:00 : Registration

3:00 - 6:00 : Tutorial, Rudy Raymond H. P. (IBM Research)

. . . . Programming IBM Superconducting Qubits with Qiskit

*** This tutorial is especially for students to learn how to work with IBM superconducting quantum computers

and scheduled on Sunday for their convenient participation.

*** You have to bring your own notebook/laptop computers to participate in hands-on tutorial.

Nov 19 (Monday)

10:00 - 11:10, Mahn-Soo CHOI (Korea U)

. . . . Superconducting Qubits and Circuit Quantum Electrodynamics

11:30 - 12:40, Yasunobu NAKAMURA (Univ of Tokyo)

. . . . Superconducting quantum circuits: quantum computing and other applications

2:00 - 3:10, Zidan WANG (U Hongkong)

. . . . Quantum emulation of topological physics using superconducting quantum circuits

3:10 - 4:20, Yonuk CHONG (KRISS)

. . . . Construction of controlled-NOT gate based on microwave-activated phase (MAP) gate in two transmon system

4:50 - 6:00, Kyungsun MOON (Yonsei U)

. . . . Microwave Circuit QED System for Quantum Information Processing

6:00, Workshop Dinner

Nov 20 (Tuesday)

10:00 - 11:10, Jaewoo JOO (U Oxford)

. . . . Hybrid algorithms on IBM online quantum computer

11:30 - 12:40, Dae-Hyun KIM (Kyungpook Ntnl U)

. . . . Low noise amplifier for quantum information processing

2:00 - 3:10, Joonsuk HUH (SKKU)

. . . . Molecular Vibronic Spectra and Gaussian Boson Sampling

3:10 - 4:20, Peter LEEK (U Oxford)

. . . . Coaxial multilayer superconducting circuits for quantum computing

Closing

Programming IBM Superconducting Qubits with Qiskit

Rudy Raymond H. P.

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I will introduce Qiskit [1], an open-source quantum information science toolkit aimed at leveraging today's quantum processors and conducting research. I will introduce elements of Qiskit emphasizing Terra, which is the code foundation at the level of quantum circuits, and Aqua, which is used for building algorithms and applications. We will walk through basic operations of quantum computing using the Qiskit Tutorials [2], and see how well-known experiments on quantum bits that can be performed on IBM Q devices by those basic operations to create quantum superposition and entanglement, such as, quantum teleportation and quantum random access coding [3]. In addition to introducing how to code textbook quantum algorithms, such as, the Bernstein-Vazirani algorithm, I will also show examples of quantum games to show the fun of programming with quantum computing. Participants are expected to obtain IBM Q accounts [4] prior to attending, and bring their own laptop computers to the talk.

References:

[1] "Qiskit". URL: https://qiskit.org
[2] "Qiskit Tutorial".
URL: https://nbviewer.jupyter.org/github/Qiskit/qiskit-tutorial/blob/master/index.ipynb
[3] "(4, 1)-Quantum random access coding does not exist—one qubit is not enough to recover one of four bits", M. Hayashi, K. Iwama, H. Nishimura, R. Raymond, and S. Yamashita, New Journal of Physics (8), 129, IOP Publishing, 2006.
URL: http://iopscience.iop.org/article/10.1088/1367-2630/8/8/129/meta
[4] "Setting the IBM Q Account". Follow the instruction at https://github.com/Qiskit/qiskit-tutorial/blob/master/INSTALL.md

Superconducting Qubits and Circuit Quantum Electrodynamics

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In this half-tutorial and half-seminal talk, the superconducting circuit quantum electrodynamics (circuit QED) is introduced as a minimal prototype model for the fundamental light-matter interaction. The basic protocols and the state of the art technologies are introduced and reviewed. We then discuss the exotic quantum states [2,4,6] due to the ultra-strong coupling between the superconducting qubits and the microwave photons in the superconducting circuit resonator. The latter also enables unprecedented sensitivity for quantum charge fluctuations in nano-scale devices [1,3,5].

References

[1] M. M. Desjardins et al., Nature 7652, 71 (2017).
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Superconducting quantum circuits: quantum computing and other applications

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Superconducting qubits have been around already for twenty years [1]. Thanks to the orders-of-magnitude improvement of the coherence time, we can now play with them various quantum operations. Integration of qubits for scalable quantum computing is a challenging but growing research field we are also involved in. In addition, microwave quantum optics based on superconducting circuits has led to a number of sophisticated techniques such as microwave single photon detectors [2,3]. As a well-controlled quantum system, superconducting qubits and resonators are also exploited in quantum information thermodynamics [4] as well as in implementations of hybrid quantum systems with collective excitations in solid, e.g., magnons in ferromagnetic materials [5] and phonons in surface acoustic wave resonators [6]. All these topics manifest the uniqueness of superconducting quantum circuits as artificially-designed macroscopic quantum objects.

References

[1] Y. Nakamura, Yu. A. Pashkin, and J. S. Tsai, Nature 398, 786 (1999).
[2] K. Inomata, Z. R. Lin, K. Koshino, W. D. Oliver, J. S. Tsai, T. Yamamoto, and Y. Nakamura, Nature Commun. 7, 12303 (2016).
[3] S. Kono, K. Koshino, Y. Tabuchi, A. Noguchi, and Y. Nakamura, Nature Physics 14, 546 (2018).
[4] Y. Masuyama, K. Funo, Y. Murashita, A. Noguchi, S. Kono, Y. Tabuchi, R. Yamazaki, M. Ueda, and Y. Nakamura, Nature Commun. 9, 1291 (2018).
[5] D. Lachance-Quirion, Y. Tabuchi, S. Ishino, A. Noguchi, T. Ishikawa, R.Yamazaki, and Y. Nakamura, Sci. Adv. 3, e1603150 (2017).
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Quantum emulation of topological physics using superconducting quantum circuits

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Symmetry and topology, as the two fundamentally important concepts in physics and mathematics, have not only manifested themselves in science, but also provided us with profound understanding of various natural phenomena. Recently, topological gapless systems, including Z2 topological metals and semimetals [1-3], have attracted increasing research interests both theoretically and experimentally. In this talk, I will first introduce basic concepts of general and symmetry-protected topological metals. Then I will report experimental manipulations of several topological semimetal bands and exotic topological currents using artificial systems [4,5].

This work was done in collaboration with Y. Yu, X. Tan, Y. X. Zhao, Q. Liu, G. Xue, H. Yu, and is partly supported by the GRF of Hong Kong (HKU173309/16P& HKU173057/17P) and the NKRDP of China (Grant No. 2016YFA0301802).

References

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[3]. Y. X. Zhao, A. P. Schnyder, and Z. D. Wang, Phys. Rev. Lett. 116, 156402 (2016).
[4]. X. Tan et al., npj Quantum Materials 2, 60 (2017).
[5]. X. Tan et al., arXiv: 1802.08371.

Construction of controlled-NOT gate based on microwave-activated phase (MAP) gate in two transmon system

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We experimentally constructed an all-microwave scheme for the controlled-NOT (cNOT) gate between two superconducting transmon qubits in a three dimensional cavity. Our cNOT gate is based on the microwave-activated phase (MAP) gate, which requires an additional procedure to compensate the accumulated phases during the operation of the MAP gate. We applied Z-axis phase gates using microwave hyperbolic secant pulse on both qubits with adequate rotation angles systematically calibrated by separate measurements. We evaluated the gate performance of the constructed cNOT gate by performing two-qubit quantum process tomography (QPT). Finally, we present the experimental implementation of the Deutsch-Jozsa algorithm using the cNOT gate.

References

[1] Scientific Reports 8:13598 (2018)

Nov 19 (Monday)
4:50 - 6:00, Kyungsun MOON (Yonsei U)

Microwave Circuit QED System for Quantum Information Processing

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I will give a review on the recent progress in microwave circuit QED system as one of the promising solid-state based architecture to realize quantum computing. The circuit QED systems consist of a superconducting qubit located inside a high-Q superconducting linear stripline resonator (LSR) or a three-dimensional waveguide cavity, which have experimentally demonstrated a strong coupling between superconducting qubit and intracavity microwave photon. This has made possible the coherent control of a superconducting qubit by a single photon and vice versa, which has been successfully applied to quantum computing and quantum optics. The strong coupling can make the unexplored regime of quantum optics readily accessible.

We theoretically demonstrate that the coherent coupling of two cavity photon modes by a qubit can generate a squeezed state of light[1,2]. We also theoretically propose a circuit QED system implemented with a triple-leg stripline resonator (TSR). Unlike from the LSR, the fundamental intracavity microwave modes of the TSR are two-fold degenerate. When a superconducting qubit is placed near one of the TSR legs, one fundamental mode is directly coupled to the qubit, while the other one remains uncoupled. Using our circuit QED system, we have theoretically studied a two-qubit quantum gate operation in a hybrid qubit composed of a flying microwave qubit and a superconducting qubit. We have demonstrated that, for the hybrid qubit, the quantum controlled phase flip gate can be reliably implemented for the experimentally available set of parameters[3].

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K. Moon, Phys. Rev. A 88 043830 (2013).
[3]“Hybrid two-qubit gate using a circuit QED system with a triple-leg stripline resonator”
Dongmin Kim and K. Moon, Phys. Rev. A 98 042307 (2018).

Hybrid algorithms on IBM online quantum computer

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A few hybrid quantum algorithms are presented. First, we investigated a practical method of performing the Harrow-Hassidim-Lloyd (HHL) algorithm solves a system of linear equations. In our hybrid scheme, a classical information feed-forward is required from the quantum phase estimation algorithm to reduce a circuit depth from the original HHL algorithm. It is experimentally examined with four qubits in the IBM Quantum Experience setups, and the experimental results of our algorithm show higher accurate performance on specific systems of linear equations than that of the HHL algorithm. Then, I will briefly introduce a new hybrid algorithm for finding a ground-state energy of nonlinear equations.

References

[1] arXiv:1807.10651

Low noise amplifier for quantum information processing

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References

[1]

Molecular Vibronic Spectra and Gaussian Boson Sampling

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Boson sampling (BS) is a multimode linear optical problem that is expected to be intractable on classical computers [1]. It was recently suggested that the molecular vibronic spectroscopy (MVS) is computationally as complex as BS. In my talk, I will present the correspondence relation between BS and MVS and briefly introduce the experimental demonstrations of the molecular spectroscopic process using quantum devices. The similarity of the two theories results in another BS setup, which is called “vibronic BS” [2-6]. The hierarchical structure of vibronic BS, which includes the original BS and other Gaussian BS, is also explained.

References

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Coaxial multilayer superconducting circuits for quantum computing

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Superconducting circuits are well established as a leading platform for the development of universal quantum computers. In order to advance to a practically useful level, architectures are needed which combine arrays of many qubits with selective qubit control and readout, without compromising on coherence. The strong coupling of superconducting qubits to microwave resonators, realising circuit quantum electrodynamics (QED), has been demonstrated to be a powerful architecture for controlling qubit coherence and implementing coupling and readout of qubits, however the circuit layout required to scale to many qubits rapidly becomes complex. In this talk I will present our work on a coaxial multilayer version of circuit QED [1] in which qubit and resonator are fabricated on opposing sides of a single chip, and control and readout wiring are provided by coaxial wiring running perpendicular to the chip plane, providing a potentially simple route to scaling to grids of many qubits.

References

[1] Rahamim *et al.*, Applied Physics Letters 110, 222602 (2017)