Joint Symposium on Quantum Computing

Abstracts

Session 1 (Regular Talk)

S1.01 (10:00 – 10:40)

Quantum Machine Learning Research at Yonsei University

Kyungdeock Daniel Park

Yonsei University

TBD

S1.02(10:40 – 11:20)

Recent achievements in Keio University Quantum Computing Center for AI application

Naoki Yamamoto

Department of Applied Physics and Physico-Informatics, Faculty of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: yamamoto@appi.keio.ac.jp

I will talk about Recent achievements in Keio University Quantum Computing Center for AI application.

S1.03 (11:20 – 12:00)

Quantum Reinforcement Learning and Quantum Classifiers

Nian-Ting Cai[1], Po-Jung Lu[1], Hsi-Sheng Goan[1,2,3]

[1]Department of Physics and Center for Theoretical Physics, National Taiwan University, Taipei 106319, Taiwan

[2] Center for Quantum Science and Engineering, National Taiwan University, Taipei 106319, Taiwan

[3]Physics Division, National Center for Theoretical Sciences, Taipei, 106319, Taiwan

Email: goan@phys.ntu.edu.tw

Quantum computing and artificial intelligence (AI; or machine learning) are undoubtedly the two hottest and most promising research fields of this century. We explore the interaction between quantum computing and machine learning, and study how to use the results and technologies of one field to solve problems in the other field. After decades of efforts in constructing practical quantum computers, we are now in the so-called noisy intermediate-scale quantum (NISQ) computer era without quantum error correction. It may still be a long way to go to realize a fully-functional error-corrected quantum computer. We investigate, in the NISQ device stage, how to use the hybrid variational quantum-classical algorithms to demonstrate evidence of possible advantages in quantum machine learning over its classical counterpart. The idea in this approach is to replace the classical neural networks with parameterized or variational quantum circuit. Specifically, we study the capability of variational quantum circuits in performing deep reinforcement tasks as well as classification jobs, showing evidence of advantage of using considerably fewer parameters in achieving similar accuracy. The proposed framework is rather general and is expected to solve complicated tasks when larger-scale quantum machines are available.

Session 2 (Regular Talk)

S2.01 (13:30 – 14:10)

Towards the fundamental limits of efficient quantum transduction

Chiao-Hsuan Wang

Department of Physics and Center for Theoretical Physics, National Taiwan University, Taipei 106319, Taiwan
Center for Quantum Science and Engineering, National Taiwan University, Taipei 106319, Taiwan
Physics Division, National Center for Theoretical Sciences, National Taiwan University, Taipei 106319, Taiwan

Email: chiaowang@phys.ntu.edu.tw

High-performance quantum transducers, which faithfully convert quantum information between disparate physical carriers, are essential in quantum science and technology. Especially in demand is quantum transduction between optical frequencies, which are ideal for low-loss transmission across long distances, and microwave frequencies, which admit high-fidelity quantum operations. In this talk, we will first present a generic formalism for N-stage quantum transduction that covers various leading experimental approaches and identify the generalized matching conditions for achieving maximum conversion efficiency.

We will then utilize quantum capacity, the highest achievable qubit communication rate through a channel, to define a single metric that unifies various criteria of a desirable transducer. Using the continuous-time quantum capacities of bosonic pure-loss channels as benchmarks, we investigate the optimal designs of generic quantum transduction schemes implemented by transmitting external signals through a coupled bosonic chain. With physical constraints on the maximal coupling rate, the highest quantum capacity is achieved by transducers with a maximally flat conversion frequency response, analogous to Butterworth electric filters.

*This work is supported by ARO (W911NF-18-1-0020, W911NF-18-1-0212), ARO MURI (W911NF-16-1-0349, W911NF-21-1-0325), AFOSR MURI (FA9550-19-1-0399, FA9550-21-1-0209), AFRL (FA8649-21-P-0781), DoE Q-NEXT, NSF (OMA-1936118, EEC-1941583, OMA-2137642), NTT Research, and the Packard Foundation (2020-71479), and the NSTC of Taiwan (111-2112-M-002-049-MY3).

S2.02(14:10 – 14:50)

Developing Applications on IBM Quantum with Partners

Yukio Kawashima

IBM Quantum, IBM Research Tokyo, Tokyo 103-8510 Japan
Email: Yukio.Kawashima@ibm.com

IBM Quantum is constantly looking for applications which will deliver scientific impact using quantum computing. We are also constantly validating across our quantum network to steer towards practical impact for our partners. Every engagement gets us one step closer to the stage where a quantum computer can solve valuable industry problems cheaper, faster, or more accurately than classical computing. Quantum partners lets us know what will be useful in the near term and where it is going to be useful in the long term. That will bring us focus on working on topics to achieve quantum advantage as soon as possible. We identified that simulating nature on quantum computer is expected to bring greater than polynomial speed up. In my talk, I would like to focus on efforts to develop applications through collaboration with industrial partners in the field of chemistry.

S2.03(15:20 – 16:00)

Quantum algorithms for the direct computation of the energy gaps of atoms and molecules

Kenji Sugisaki

Graduate School of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: ksugisaki@keio.jp

Solving a Schrödinger equation of atoms and molecules is one of the ultimate goals of quantum chemistry and physics. The full configuration interaction (full-CI) method is known to provide variationally best possible wave function within a given basis set, but the computational cost of the full-CI calculations grows exponentially with the system size. The quantum phase estimation (QPE) algorithm is capable of calculating the full-CI energy on a quantum computer in polynomial time.[1] Although the quantum circuit for QPE is too deep to execute on a NISQ device, it is regarded as one of the most powerful approaches for quantum chemical calculations in the FTQC era.

It is worth noting that almost all the problems relevant to quantum chemical calculations focus on the energy differences between two electronic states or structures, rather than the total energies themselves. In this talk, we introduce a Bayesian phase difference estimation (BPDE) algorithm,[2] a general quantum algorithm for the direct calculation of energy gap by utilizing quantum superposition of the electronic ground and the excited states. Applications of the BPDE algorithm to the vertical excitation energies,[2] total energies,[3] numerical energy gradients,[4] and relativistic energy difference (fine structure splitting)[5] will be discussed.

[1] A. Aspuru-Guzik, A. D. Dutoi, P. J. Love, M. Head-Gordon, Science 2005, 309, 1704.
[2] K. Sugisaki et al, Phys. Chem. Chem. Phys. 2021, 23, 20152.
[3] K. Sugisaki et al, J. Phys. Chem. Lett. 2021, 12, 11085.
[4] K. Sugisaki et al, J. Phys. Chem. Lett. 2022, 13, 11105.
[5] K. Sugisaki et al, arXiv:2212.02058.

Session 3 (Short Talk)

S3.01(16:00 – 16:15)

Quantum channel decomposition with pre- and post-selection

Ryo Nagai

Center for Exploratory Research, Research and Development Group, Hitachi, Ltd.,
Kokubunji, Tokyo, 185-8601, Japan
Keio University, Yokohama 223-8522 Japan
Email: ryo.nagai@quantum.keio.ac.jp

The quantum channel decomposition techniques, which contain the so-called probabilistic error cancellation and gate/wire cutting, are powerful approach for simulating a hard-to-implement (or an ideal) unitary operation by concurrently executing relatively easy-to-implement (or noisy) quantum channels. However, such virtual simulation necessitates an exponentially large number of decompositions, thereby significantly limiting their practical applicability. We propose a channel decomposition method for target unitaries that have their input and output conditioned on specific quantum states, namely unitaries with pre- and post-selection. Specifically, we explicitly determine the requisite number of decomposing channels, which could be significantly smaller than the selection-free scenario. Furthermore, we elucidate the structure of the resulting decomposed unitary. We demonstrate an application of this approach to the quantum linear solver algorithm, highlighting the efficacy of the proposed method.

This talk is based on arXiv: 2305.11642 [quant-ph]

S3.02(16:15– 16:30)

Hexagonal lattice with circuit QED system by triple-leg stripline resonator

Dongmin Kim[1], Jun-won Rhim[2], Kyungsun Moon[1]

[1]Department of Physics and IQIT, Yonsei Univ., Seoul 03722, Korea
[2]Department of Physics, Ajou University, Suwon 16499, Korea
Email: tsr@yonsei.ac.kr

In circuit QED system, a flat band has been observed in Kagome Lattices and Lieb Lattices with tunable hopping strengths coupled superconducting resonators. In this study, we investigate various geometric aspects of a graphene-like hexagonal optical lattice which has upper and lower flat band with Triple-leg stripline resonators (TSRs). The inherent two-fold degenerate modes of the TSR resemble a behavior of orbitals in 2D lattice systems. Our analysis reveals how the system leverages the destructive interference to establish flat bands via stabilized compact localized states (CLSs). We further explore the real-space topology corresponding to the flat bands by finding proper non-contractible loop states (NLSs). Additionally, in a zigzag-structured hexagonal lattice, we demonstrate the induction of flat edge modes at zero energy by calculating the Zak phase. We also elucidate the origin of other dispersive edge bands that arise from the singular point of the flat band.

S3.03(16:30 – 16:45)

Accurate Harmonic Vibrational Frequencies for Diatomic Molecules via Quantum Computing

Shih-Kai Chou[1], Jyh-Pin Chou[2,3], Alice Hu[4,5], Yuan-Chung Cheng[6,7,3], Hsi-Sheng Goan[1,7,3]

[1]Department of Physics and Center for Theoretical Physics, National Taiwan University, Taipei 106319, Taiwan

[2]Department of Physics, National Changhua University of Education, Changhua 50007, Taiwan

[3]Physics Division, National Center for Theoretical Sciences, Taipei, 106319, Taiwan

[4]Department of Mechanical Engineering, City University of Hong Kong, Kowloon, Hong Kong SAR 999077, China

[5]Department of Materials Science and Engineering, City University of Hong Kong, Kowloon, Hong Kong SAR 999077, China

[6]Department of Chemistry, National Taiwan University, Taipei 106319, Taiwan

[7]Center for Quantum Science and Engineering, National Taiwan University, Taipei 106319, Taiwan

Email: goan@phys.ntu.edu.tw

During the noisy intermediate-scale quantum (NISQ) era, quantum computational approaches refined to overcome the challenge of limited quantum resources are highly valuable. A comprehensive benchmark for a quantum computational approach in this spirit could provide insights toward further improvements. In this work, we present such an investigation by benchmarking harmonic vibrational frequencies for 43 diatomic molecules via the variational quantum eigensolver algorithm in the noiseless situation. Using the accurate Hamiltonian constructed from Kohn-Sham orbitals expanded in the Daubechies wavelet basis set, where a compact active space is further selected to reduce the number of qubits required, we show that the results from the exact diagonalization of qubit Hamiltonians agree with the experimental data and chemistry-inspired UCCSD could achieve the same accuracy except for systems whose Mayer bond order indices are larger than 2. For those systems, we then demonstrate that the heuristic hardware-efficient RealAmplitudes ansatz can provide significant improvement over the UCCSD ansatz, verifying that the harmonic vibrational frequencies could be calculated accurately by quantum computation in the NISQ era.

S3.04(16:45 – 17:00)

Quantum computing quantum Monte Carlo with hybrid tensor network toward electronic structure calculations of large-scale molecular and solid systems

Shu Kanno

Mitsubishi Chemical Corporation, Science & Innovation Center, Yokohama, 227-8502, Japan
Keio University, Yokohama 223-8522 Japan
Email: shu.kanno@quantum.keio.ac.jp

Quantum computers are expected to solve quantum chemistry and materials science problems more accurately than classical computers. Quantum Computing Quantum Monte Carlo (QC-QMC) is a method that combines with a quantum algorithm such as variational quantum eigensolver (VQE) and can obtain the ground state more accurately with fewer quantum resources than VQE or QMC alone. Here, we present an algorithm that combines QC-QMC with a hybrid tensor network (HTN), we name it HTN+QMC. In the HTN with a two-layer quantum tree tensor structure, only n-qubit excluding ancilla qubits is required when preparing reference wave function of O(n^2) qubits. Full configuration interaction QMC is adopted as an example of QMC, and the proposed algorithm is applied to the Heisenberg chain model, the graphite-based Hubbard model, the hydrogen plane model, and MonoArylBiImidazole (MABI). The results show that the algorithm can achieve several orders of magnitude higher energy accuracy than VQE or QMC alone. Moreover, when the system is properly decomposed, the energy accuracy of HTN+QMC is comparable to that of QC-QMC. These results pave the way for large-scale and highly accurate electronic structure calculations using current quantum devices.

This talk is based on arXiv: 2303.18095.

S3.05(17:00 – 17:15)

Possible Design Flaw of the Sublinear-Resource Quantum Integer Factoring Algorithm

Hao-Yu Chung[1] and Hsi-Sheng Goan[1,2,3]

[1]Department of Physics and Center for Theoretical Physics, National Taiwan University, Taipei 10617, Taiwan
[2]Center for Quantum Science and Engineering, National Taiwan University, Taipei 10617, Taiwan
[3]Physics Division, National Center for Theoretical Sciences, Taipei, 10617, Taiwan

Email: r09222027@ntu.edu.tw

The security of many widely used cryptographic systems, such as the RSA algorithm, relies on the difficulty of factoring large integers. In 1994, mathematician Peter Shor developed a quantum algorithm for factoring integers that is exponentially faster than classical algorithms. However, due to technical limitations of noisy intermediate-scale quantum (NISQ) computing devices, Shor's algorithm has not been implemented on a large scale yet.

In Dec. 2022, Yan et al. presented the sublinear-resource quantum integer factoring (SQIF) algorithm, a new way to factor integers with quantum optimization methods, which is presumably not as demanding and therefore more likely to be implemented in the near term in comparison to Shor's algorithm. The proposed method reduces integer factorization to closest vector problems (CVPs) and utilizes quantum approximate optimization algorithm (QAOA) to solve the CVPs.

While the authors claimed that the qubits required is sublinear in the bit length of integer N, they did not discuss the time complexity of the algorithm. We present evidence showing that the SQIF algorithm, even with extremely fast and accurate QAOA subroutines, would still run slower than quadratic sieve. This result indicates the possible design flaw in the SQIF algorithm that aims to solve integer factorization by reducing them to CVPs.

S3.06(17:15 – 17:30)

Low-rank Quantum State Preparation

Israel Araujo
Yonsei University

TBD

Session 4 (Regular Talk)

S4.01 (09:00 – 09:40)

Research on Using Digital Computers for Quantum Computers

Won Woo Ro

School of Electical and Electronic Engineering, Yonsei Unviersity, Seoul, Korea
Email: wro@yonsei.ac.kr

TBD

S4.02 (09:40 – 10:20)

Towards the Fundamental Limits of Efficient Quantum Transduction

Youngseok Kim

IBM Quantum, IBM Thomas J. Watson Reearch Center, Yorktown Heights, NY, USA
Email: youngseok.kim1@ibm.com

One of the biggest impediments for achieving useful quantum computing is noise. The widely accepted solution to this challenge is fault-tolerant quantum circuits, however, it is out of reach for currently available processors to achieve computation at utility scale. Instead, we argue that quantum error mitigation enables access to accurate expectation values even on existing, noisy quantum computers. Establishing the applicability of these techniques at scales beyond those accessible to brute force classical methods is a crucial step toward probing a computational advantage with near-term noisy quantum computers. Here we experimentally demonstrate the efficacy of an error mitigation technique, zero-noise extrapolation, for quantum circuits using up to 127 qubits. The accuracy of the mitigated expectation values is greatly enhanced by novel advances in the coherence of large-scale superconducting quantum processors, and the ability to controllably scale noise at this scale. These experiments demonstrate an important tool for the realization of near-term quantum applications in a pre-fault tolerant era.

reference: https://www.nature.com/articles/s41586-023-06096-3

Session 5 (Regular Talk)

S5.01(10:40 – 11:20)

Research progress of financial team at Keio University Quantum Computing Center

Yohichi Suzuki

Graduate School of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: suzuki.yohichi@keio.jp

We will introduce the research activities of the Financial Team of the Center for Quantum Computing at Keio University. The main content of our talk will be about quantum amplitude estimation. This method is one of the important quantum algorithms that have been proposed for various applications such as Monte Carlo simulation and machine learning. This method is known to be an efficient algorithm compared to classical computation. On the other hand, when considering the execution of this algorithm on the current Noisy Intermediate Scale Quantum (NISQ) device, it is important to construct an algorithm that takes the number of qubits, the limitation of computable time, and the effect of noise into account. We propose an algorithm that takes these limitations into account and is still efficient compared to classical computation [1,2,3]. If time allows, we will give a talk on how to encode data into a quantum computer. In general, encoding classical data into a quantum computer requires an exponential number of gates with respect to the number of qubits. We propose a method to reduce the number of gates needed to encode data by building shallow circuits via machine learning [4,5].

1. Y. Suzuki, S. Uno, R. Raymond, T. Tanaka, T. Onodera, and N. Yamamoto. Amplitude estimation without phase estimation. *Quantum Information Processing*, Vol. 19, No. 2, p. 75, 2020.
2. T. Tanaka, Y. Suzuki, S. Uno, R. Raymond, T. Onodera, and N. Yamamoto. Amplitude estimation via maximum likelihood on noisy quantum computer. *Quantum Information Processing*, Vol. 20, No. 9, pp. 1–29, 2021.
3. T. Tanaka, S. Uno, T. Onodera, N. Yamamoto, and Y. Suzuki. Noisy quantum amplitude estimation without noise estimation. *Phys. Rev. A*, Vol. 105, p. 012411, 2022.
4. K. Nakaji, S. Uno, Y. Suzuki, R. Raymond, T. Onodera, T. Tanaka, H. Tezuka, N. Mitsuda, N. Yamamoto. Approximate amplitude encoding in shallow parameterized quantum circuits and its application to financial market indicators. *Physical Review Research*, 4, 2, 023136, 2022
5. N. Mitsuda, K. Nakaji, Y. Suzuki, T. Tanaka, R. Raymond, H. Tezuka, T. Onodera, N. Yamamoto. Approximate complex amplitude encoding algorithm and its application to classification problem in financial operations. arXiv:2211.13039

S5.02 (11:20 – 12:00)

Private Communication over Quantum Wiretap Channels

Hao-Chung Cheng

Department of Electrical Engineering, National Taiwan University, Taipei 106319, Taiwan
Center for Quantum Science and Engineering, National Taiwan University, Taipei 106319, Taiwan
Physics Division, National Center for Theoretical Sciences, National Taiwan University, Taipei 106319, Taiwan
Email: haochung.ch@gmail.com

When sending information through a quantum wiretap channel, an eavesdropper may have access to the quantum side information correlated to the transmitted information. Hence, designing an appropriate coding strategy for bounding the information leakage to the eavesdropper is fundamental in information-theoretic security. In this talk, we will show a technique called quantum soft covering to analyze the secrecy exponent of private communication over quantum wiretap channels. This talk is based on arXiv:2202.10995 and arXiv:2304.12055.

Poster presentation

P. 01

A new information criterion for quantum state estimation

Hiroshi Yano

Department of Applied Physics and Physico-Informatics, Graduate School of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: hiroshi.yano.gongon@keio.jp

Quantum state estimation (or state tomography) is an indispensable task in quantum information processing. Because full state tomography that determines all elements of the density matrix is computationally demanding, one usually takes the strategy of assuming a certain model of quantum states and identifying the model parameters. However, it is difficult to make a valid assumption given little prior knowledge on a quantum state of interest, and thus we need a reasonable model selection method for quantum state estimation. Actually, in the classical statistical estimation theory, several types of information criteria have been established and widely used in practice for appropriately choosing a classical statistical model. In this study, we propose quantum information criteria for evaluating the quality of the estimated quantum state in terms of the quantum relative entropy, which is a natural quantum analogue of the classical information criterion defined in terms of Kullback–Leibler divergence.

This poster is based on arXiv:2304.10949.

P. 02

Optimal parallel wire cutting without ancilla qubits

Hiroyuki Harada

Department of Applied Physics and Physico-Informatics, Graduate School of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: hiro.041o_i7@keio.jp

The quantum circuit cutting techniques are widely used to execute quantum algorithms that require more qubits than physically available; the idea is to decompose the original circuit to smaller sub-circuits that are combined to simulate the original one by sampling. However, they suffer from an inevitable issue that the sampling cost exponentially grows with the number of cuts, and thus it is practically important to develop decomposition methods working with smaller sampling cost. This paper focuses on the parallel wire-cutting problem, meaning that the target to cut is the identity channel acting on multiple qubits in parallel. There are two

previous studies. The first one is a teleportation-based method that achieves this task with the use of ancilla qubits, whose sampling cost was proven to be optimal. The second one uses the technique of classical shadow to solve the problem without any ancilla qubits, which however does not achieve the optimal sampling cost. This paper gives a definitive solution to this problem. That is, we develop the optimal parallel wire cutting without ancilla qubits, in the same setup as that taken in the above previous studies. Moreover, the developed ancilla-free method can be applied to the non-parallel case, which also improves the sampling cost obtained in the previous study.

This poster is based on arXiv:2303.07340.

P. 03

Quantum Random Access Optimization Under Noise

Kentaro Tamura

Department of Applied Physics and Physico-Informatics, Graduate School of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: cicero@keio.jp

Quantum random access optimization (QRAO) is an algorithm for solving combinatorial optimization problems that reduces the number of qubits required to encode a problem by utilizing quantum random access codes (QRAC). With the 3-1 QRAC encoding, a maximum of 3 binary variables can be encoded per qubit. This reduces the number of qubits required to solve a problem by 1/3 at best compared to methods such as the quantum approximate optimization algorithm (QAOA), where a single binary variable is encoded per qubit. QRAO constructs a Hamiltonian corresponding to a problem using QRAC, finds a candidate maximum eigenstate with the variational quantum eigensolver (VQE), and recovers the classical solution through a process called rounding. While the reduction of the number of qubits involved is expected to enhance the quality of the candidate maximum eigenstate obtained via VQE, the approximation ratio of the classical solution is ultimately determined by rounding. In the present study, we investigate the effect of depolarizing noise on the approximation ratio obtained by QRAO, with the MaxCut problem as an example.

This poster is based on arXiv:2111.03167.

P. 04

Measurement Based Quantum Reservoir Computing

Toshiki Yasuda

Department of Applied Physics and Physico-Informatics, Graduate School of Science and Technology
Keio University, Yokohama 223-8522 Japan
Email: toshiki-yasuda0113@keio.jp

Reservoir computing is a machine learning framework that uses artificial or physical dissipative dynamics to predict time-series data using nonlinearity and memory properties of dynamical systems. Quantum systems are considered as promising reservoirs, but the conventional quantum reservoir computing (QRC) models have problems in the execution time and resulting computing performance. In this study, we develop a quantum reservoir system that exploits repeated measurement to generate a time-series. We experimentally execute the proposed QRC on the IBM's quantum superconducting device and show that it achieves higher accuracy and shorter execution time than the conventional QRC method in some time-series prediction tasks. Furthermore, we study the temporal information processing capacity to quantify the computational capability of the proposed quantum reservoir; in particular, we use this quantity to identify the measurement strength that best tradeoffs the amount of available information and the strength of dissipation. An experimental demonstration with soft robot is also provided.

Black-Litterman Portfolio Optimization with Noisy Intermediate-Scale Quantum Computer

Chi-Chun Chen [1,2,3], San-Lin Chung [4,5], and Hsi-Sheng Goan [1,3,6]

[1]Department of Physics, National Taiwan University, Taipei City 106319, Taiwan
[2]MediaTek, Hsinchu 30078, Taiwan
[3]Physics Division, National Center for Theoretical Science, Taipei 106319, Taiwan
[4]Department of Finance, National Taiwan University, Taipei 106319, Taiwan
[5]Department of Digital Financial Technology, Chang Gung University, Taoyuan 33302, Taiwan
[6]Center for Quantum Science and Engineering, National Taiwan University, Taipei 106319, Taiwan
Email:goan@phys.ntu.edu.tw

Portfolio optimization is one of the highly concerning problems that quantum computers might have a potential advantage to solve. In this work, rather than using the commonly seen modern portfolio theory (MPT) model, we show how noisy intermediate-scale quantum (NISQ) algorithms can be applied to Black-Litterman (BL) portfolio optimization model. We demonstrated a walk-forward backtesting case for 9 continuous time periods, using real world price data. Our backtesting results show that the exact solution of BL model outperforms the index, MPT model, and the naive portfolio (equal weighted) for a long continuous time sequence. We also show that the solution obtained from VQE and QAOA with approximate ratio (AR) high enough can perform similarly or even better in backtesting. Finally, we argue by comparing the probability of obtaining a "good" solution from random sampling that one

should use very few final samplings once the parameters in the ansatz are optimized. We also point out the significance of reducing classical computational cost in evaluating Ising Hamiltonian expectation value on the way to quantum advantage

P. 06

Synthesis of Rotation Operations for Fault-Tolerant Quantum Computation

Tian-Fu Chen, Cheng-Han Liu, and Jie-Hong R. Jiang
Graduate School of Advanced Technology and Graduate Institute of Electronics Engineering
National Taiwan Univesity, Taipei 106216 Taiwan
Center for Quantum Science and Engineering, National Taiwan University, Taipei 10617, Taiwan
Physics Division, National Center for Theoretical Science, Taipei 106319, Taiwan
Email: d11k42001@ntu.edu.tw

Rotation operations are essential ingredients in quantum algorithms. However, fault-tolerant quantum computation is intrinsically digital, based on a finite set of primitive gates, and thus cannot provide an analog rotation operation with arbitrary angles. It must resort to approximating a rotation operation using a basic universal gate set. Prior work on rotation synthesis either focuses on synthesizing individual rotations without considering a quantum circuit as a whole or is restricted to the specific quantum Fourier transform circuit. In this work, we develop a holistic and general approach to rotation synthesis taking all rotation operations of a circuit into account for quantum cost minimization. Experimental results demonstrate the superiority of our method compared to existing methods in reducing the cost of synthesized quantum algorithms with rotation operations.

*This work is supported by the National Science and Technology Council of Taiwan under grants 111-2119-M-002-012 and 112-2119-M-002-017 and the Ministry of Education of Taiwan under grants 112L900903.

P. 07

Effective Hamiltonian for Cross-Cross Resonance gate and Frequency tuning in Transmon qubits

Yousung Kang and Kyungsun Moon

Department of Physics and Institute of Quantum Information Technology,
Yonsei University, Seoul 03722 Korea
Email: kmoon@yonsei.ac.kr

Two-qubit entangler is one of the most important components for quantum computer. For a quantum computer based on transmon qubit, the Cross-Cross Resonance(CCR) gate has been recently proposed, which seems to operate faster than Cross-Resonance(CR) gate as an iSWAP gate. However, unlike the CR gate, the CCR gate needs a frequency change induced by Stark shift. Here, we present the theoretical study of CCR gate in transmon qubits. Using the Schrieffer–Wolff transformation and rotating-wave approximation, we obtain both the effective Hamiltonian for CCR gate and the frequency condition of CCR gate. We also perform numerical simulation using Quantum Toolbox in Python(QuTip). Our numerical simulation result shows an excellent agreement with the analytical one.

*This work is supported by the National Research Foundation of Korea (grant number NRF-2022M3K2A108385811).

Circuit QED system with Triple-Leg Stripline Resonator

Dongmin Kim and Kyungsun Moon

Department of Physics and Institute of Quantum Information Technology
Yonsei University, Seoul 03722 Korea
Email: kmoon@yonsei.ac.kr

We have theoretically proposed a new circuit QED system implemented with a triple-leg stripline resonator (TSR). Unlikely from the LSR, the fundamental intra-cavity 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.

Conventional linear stripline resonators (LSR) have been used to build several interesting lattice structures including 2D Kagome and Lieb lattice. However, due to its structural limitations, it is hard to fabricate honeycomb lattice structures using the LSR. In contrast, our TSR can form an optical honeycomb lattice, since each resonator can be symmetrically connected to the three adjacent ones. We study the photonic honeycomb lattice nanoribbon, which exhibits a flat band, whose structure is complement to that of zigzag graphene nanoribbon in momentum space. By lateral coupling to qubits, we demonstrate that the dispersion of the edge states becomes linear and the slope of the linear dispersion is tunable by adjusting the coupling strength to the laterally placed qubits.

*This work is supported by the National Research Foundation of Korea (grant number NRF-2022M3K2A108385811).

Circuit Depth-aware Transformation for Monte Carlo Tree Search with Noisy Intermediate-Scale Quantum Computers

U.M. Lee, H.S. Jung, P. Yadav, J.Y. Lee, and Shiho Kim

School of Integrated Technology and Institute of Quantum Information Technology
Yonsei University, South Korea

In Noisy Intermediate-scale Quantum (NISQ) devices, the available number of qubits and their connectivity in the Quantum Processing Unit (QPU) are limited. As a result, the introduction of additional gates to a quantum circuit leads to an increase in both the circuit's depth and size, which in turn results in a reduction of the quantum circuit's fidelity. To mitigate this issue, minimizing the number of gates added during the quantum circuit conversion process becomes crucial. Our approach proposes an efficient method to transform the quantum Monte Carlo tree search circuit by applying various techniques to optimize the process.

Quantum Leap: Advantage of generalization performance of QML and Quantum-enhanced experimental validation

H.S. Jung, U.M. Lee, P. Yadav, J.Y. Lee, and Shiho Kim

School of Integrated Technology and Institute of Quantum Information Technology
Yonsei University, South Korea

One of the critical advantages of Quantum Machine Learning (QML) is its potential to enhance generalization performance compared to classical machine learning algorithms significantly. In classical machine learning, generalization refers to the ability of a trained model to perform well on unseen data that was not part of the training set. However, traditional models can struggle with generalization when dealing with highly complex and noisy datasets. Quantum algorithms can harness ML models to explore complex data landscapes better and find optimal solutions, resulting in improved generalization performance. The advantages of QML, such as improved generalization performance and quantum-enhanced experimental validation, open up exciting opportunities for solving complex problems in various fields, including chemistry, materials science, cryptography, and optimization. As quantum computing technology advances, we can expect even more significant leaps in performance and groundbreaking applications in the near future.

Quantum Walk-based Node Search in a Binary Tree

P. Yadav, J.Y. Lee, U.M. Lee, H.S. Jung, and Shiho Kim

School of Integrated Technology and Institute of Quantum Information Technology
Yonsei University, South Korea

The common practice of formulating a computational problem as a search problem involves defining a state space, an initial state, and a goal state. Classical algorithms like Depth-first search, Breadth-first search, and A* search are widely used to solve such problems. However, the emergence of quantum algorithms has shown promise in tackling complex computational problems, including search problems, with significantly reduced time complexity compared to

classical methods. Among the quantum algorithms, Quantum Walk stands out as a crucial approach, acting as a universal model for quantum computation. Our study explored the potential of developing a quantum-walk-based algorithm to search for a marked node within a binary tree maze environment. We also conducted a performance comparison with the classical depth-first search algorithm. Through this investigation, we aim to demonstrate the advantages and potential of quantum algorithms, notably Quantum Walk, in optimizing search tasks and solving computational problems efficiently compared to classical methods.

P. 12

Tak Hur : Neural Quantum Embedding: Pushing the Limits of Quantum Supervised Learning

P. 13

Myeonghwan Seong : Hamiltonian formulation of unsupervised data clustering

P. 14

ChangWon Lee : Scalable quantum measurement error mitigation via conditional independence and transfer learning

P. 15

Hyeondo Oh : Quantum support vector data description for anomaly detection