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RESEARCH HIGHLIGHT

12 superconducting qubits for quantum walks

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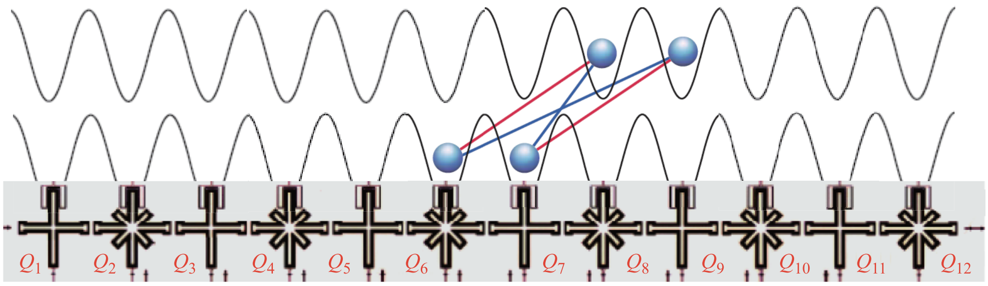
Superconducting qubits are among the most promising candidates to build a quantum computer, which is beyond the current computers [1]. Presently, the number of qubits for a superconducting quantum processor are around the order of 9–22 qubits [2–6], and devices with more superconducting qubits are reported under development. The superconducting quantum processor is a representative for the near term technologies of noisy intermediate-scale quantum computing (NISQ). It possesses intermediate-scale number of qubits and long coherence time, the fidelities for operations, logical gates and readout are relatively high. However, they are not good enough to go beyond the threshold for fault-tolerant and scalable quantum computation with quantum error corrections. Those facts imply that the current superconducting quantum processor can perform limited tasks, even it is presently one of the leading platforms for quantum computation. In this case, the specifically designed, device dependent schemes which are experimentally achievable are in demanding. For example, we can use multi-qubit superconducting quantum processor to simulate non-trivial physics, which does not need arbitrary high precision within limited coherence time.

Recently, the strongly correlated quantum walks are implemented with a one-dimensional array of 12 qubits superconducting quantum processor [7]. The quantum walks are quantum counterparts of classical random walks, which are applicable for universal quantum computation. In the past years, the implementations of quantum walks are realized in different platforms. A benchmark of the one-particle quantum walks is the propagation of correlations, for either the classical by showing the correlation in Z direction or quantum by showing entanglement. The previous results about propagation of correlations include the classical correlation with non-deterministic 10-18 atoms [8] and 11 trapped ions [9], quantum correlation with 7 trapped ions [10]. There are rich physics related with two-particle quantum walks, for example, the two particles in the quantum walks can be independent or correlated with repulsive or attractive interactions such that phenomena of bunching or anti-bunching happened generally for photons can be demonstrated [11].

In the experiments presented in Ref. [7], the one-particle and two-particle quantum walks are realized in various situations. The one-particle quantum walks are realized by flip a qubit after initialization and create an excitation. The two-particle quantum walks can be similarly realized by creating two excitations. After the states preparation with excitations, the system will evolve unitarily resulting in expected results. For one-particle quantum walks, the propagations of quantum information including entanglement are shown precisely. We can find that the propagations of different physical quantities can be described by Lieb–Robinson bounds which are analogous to light-cone phenomenon. The anti-bunching is shown in two-particle quantum walks due to strongly correlated excitations. The highlights of the quantum walks implemented in the superconducting quantum processor are as follows: Entanglement propagation can be shown clearly so that in addition to the main wavefronts, we can also observe the sub-wavefronts and the reflecting wavefronts, representing high precision of the experiments with the state-of-the-art 12 qubits quantum processor. Realization of anti-bunching is achieved by superconducting qubits which are artificial atoms, where the qubits themselves do not move while the excitations are walking. The above highlights of the experiments stress the precise manipulation and flexibility of the platforms, details of the results can be found in Ref. [7].

The remarkable advantages of quantum simulation by superconducting quantum processor are, for examples, as follows: The system operates with programmable controlling parameters such that the emulated physics range over a large regime in which different phenomena may arise such as quantum phase transitions across critical points. The system friendly interface also facilitates cloud operations which may be a priority for practical quantum computation. Similar as other platforms, the present superconducting quantum processor is particularly suitable in



studying dynamics of quantum many-body systems. Actually, the time evolution of the system state can be readout by state tomography which is maturity for superconducting quantum computation [7, 12]. The realization of quantum walks with a 12-qubit quantum processor [7] reiterates superconducting qubits as the leading candidates for a practical universal quantum computer.

References

1. C. Neill, P. Roushan, K. Kechedzhi, S. Boixo, S. V. Isakov, V. Smelyanskiy, A. Megrant, B. Chiaro, A. Dunsworth, K. Arya, R. Barends, B. Burkett, Y. Chen, Z. Chen, A. Fowler, B. Foxen, M. Giustina, R. Graff, E. Jeffrey, T. Huang, J. Kelly, P. Klimov, E. Lucero, J. Mutus, M. Neeley, C. Quintana, D. Sank, A. Vainsencher, J. Wenner, T. C. White, H. Neven, and J. M. Martinis, A blueprint for demonstrating quantum supremacy with superconducting qubits, *Science* 360(6385), 195 (2018)
2. C. Song, K. Xu, W. Liu, C. Yang, S. B. Zheng, H. Deng, Q. Xie, K. Huang, Q. Guo, L. Zhang, P. Zhang, D. Xu, D. Zheng, X. Zhu, H. Wang, Y. A. Chen, C. Y. Lu, S. Han, and J. W. Pan, 10-qubit entanglement and parallel logic operations with a superconducting circuit, *Phys. Rev. Lett.* 119(18), 180511 (2017)
3. P. V. Klimov, J. Kelly, Z. Chen, M. Neeley, A. Megrant, B. Burkett, R. Barends, K. Arya, B. Chiaro, Y. Chen, A. Dunsworth, A. Fowler, B. Foxen, C. Gidney, M. Giustina, R. Graff, T. Huang, E. Jeffrey, E. Lucero, J. Y. Mutus, O. Naaman, C. Neill, C. Quintana, P. Roushan, D. Sank, A. Vainsencher, J. Wenner, T. C. White, S. Boixo, R. Babbush, V. N. Smelyanskiy, H. Neven, and J. M. Martinis, Fluctuations of energy-relaxation times in superconducting qubits, *Phys. Rev. Lett.* 121(9), 090502 (2018)
4. M. Gong, M. C. Chen, Y. Zheng, S. Wang, C. Zha, H. Deng, Z. Yan, H. Rong, Y. Wu, S. Li, F. Chen, Y. Zhao, F. Liang, J. Lin, Y. Xu, C. Guo, L. Sun, A. D. Castellano, H. Wang, C. Peng, C. Y. Lu, X. Zhu, and J. W. Pan, Genuine 12-qubit entanglement on a superconducting quantum processor, *Phys. Rev. Lett.* 122(11), 110501 (2019)
5. C. Song, K. Xu, H. K. Li, Y. R. Zhang, X. Zhang, W. X. Liu, Q. J. Guo, Z. Wang, W. H. Ren, J. Hao, H. Feng, H. Fan, D. N. Zheng, D. W. Wang, H. Wang, and S. Y. Zhu, Observation of multi-component atomic Schrödinger cat states of up to 20 qubits, arXiv: 1905.00320 (2019)
6. K. X. Wei, I. Lauer, S. Srinivasan, N. Sundaresan, D. T. McClure, D. Toyli, D. C. McKay, J. M. Gambetta, and S. Sheldon, Verifying multipartite entangled GHZ states via multiple quantum coherences, arXiv: 1905.05720 (2019)
7. Z. Yan, Y. R. Zhang, M. Gong, Y. Wu, Y. Zheng, S. Li, C. Wang, F. Liang, J. Lin, Y. Xu, C. Guo, L. Sun, C. Z. Peng, K. Xia, H. Deng, H. Rong, J. Q. You, F. Nori, H. Fan, X. Zhu, and J. W. Pan, Strongly correlated quantum walks with a 12-qubit superconducting processor, *Science* 364(6442), 753 (2019)
8. M. Cheneau, P. Barmettler, D. Poletti, M. Endres, P. Schauß, T. Fukuhara, C. Gross, I. Bloch, C. Kollath, and S. Kuhr, Light-cone-like spreading of correlations in a quantum many-body system, *Nature* 481(7382), 484 (2012)
9. P. Richerme, Z. X. Gong, A. Lee, C. Senko, J. Smith, M. Foss-Feig, S. Michalakis, A. V. Gorshkov, and C. Monroe, Non-local propagation of correlations in quantum systems with long-range interactions, *Nature* 511(7508), 198 (2014)
10. P. Jurcevic, B. P. Lanyon, P. Hauke, C. Hempel, P. Zoller, R. Blatt, and C. F. Roos, Quasiparticle engineering and entanglement propagation in a quantum many-body system, *Nature* 511(7508), 202 (2014)
11. P. M. Preiss, R. Ma, M. E. Tai, A. Lukin, M. Rispoli, P. Zupancic, Y. Lahini, R. Islam, and M. Greiner, Strongly correlated quantum walks in optical lattices, *Science* 347(6227), 1229 (2015)
12. K. Xu, J. J. Chen, Y. Zeng, Y. R. Zhang, C. Song, W. Liu, Q. Guo, P. Zhang, D. Xu, H. Deng, K. Huang, H. Wang, X. Zhu, D. Zheng, and H. Fan, Emulating many-body localization with a superconducting quantum processor, *Phys. Rev. Lett.* 120(5), 050507 (2018)