

Candidate Course Project Topics (CMSC 657)

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Abstract

This document is meant to provide some useful guideline and references for finding projects in the field of quantum information and computation. The selection is *not comprehensive* and subject to the author's personal knowledge on the topics (mistakes are possible). Each topic comes with a brief description and a few representative references.

It is totally fine to pursue project topics beyond this document. However, please do identify your topic and relevant references in your proposal. Please feel free to contact me if you have difficulty identifying a project topic.

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1 Quantum Information & Foundation

1. Understanding of quantum time-space and casual structure.
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- Longer-Baseline Telescopes Using Quantum Repeaters. by Daniel Gottesman, Thomas Jennewein, and Sarah Croke. Phys. Rev. Lett. 109, 070503. arXiv: 1107.2939.
 - Enhanced Sensitivity of Photo-detection via Quantum Illumination. by Seth Lloyd, Science 12 Sep 2008: Vol. 321, Issue 5895, pp. 1463-1465. arXiv: 0803.2022.
2. Quantum information, blackholes, and high energy physics.
 - Black holes as mirrors: quantum information in random subsystems by Patrick Hayden and John Preskill, Journal of High Energy Physics 0709:120, arXiv:0708.4025.
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3 Quantum Algorithms

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 - J. Kempe, Quantum random walks – an introductory overview. arXiv: quant-ph/0303081
 - A. Ambainis, Quantum walks and their algorithmic applications. arXiv: quant-ph/0403120
 - F. Magniez, A. Nayak, J. Roland, and M. Santha, Search via Quantum Walk. arXiv: quant-ph/0608026
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 - Quantum linear systems algorithm with exponentially improved dependence on precision by Andrew M. Childs, Robin Kothari, Rolando D. Somma, QIP 2016. arXiv:1511.02306
 - Quantum Algorithms for Approximating the Effective Resistances in Electrical Networks by Guoming Wang. arXiv:1311.1851.
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 - Quantum Data Fitting by Nathan Wiebe, Daniel Braun, Seth Lloyd, Phys. Rev. Lett. 109, 050505 (2012). arXiv:1204.5242.
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- A subexponential-time quantum algorithm for the dihedral hidden subgroup problem by Greg Kuperberg, *SIAM Journal on Computing*, Volume 35 Issue 1, 2005, Pages 170-188. arXiv:quant-ph/0302112
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 - A quantum algorithm for computing the unit group of an arbitrary degree number field by Kirsten Eisentrger, Sean Hallgren, Alexei Kitaev, Fang Song, *STOC* 2014.
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 - Andris Ambainis, Aleksandrs Belovs, Oded Regev, Ronald de Wolf. Efficient Quantum Algorithms for (Gapped) Group Testing and Junta Testing. arXiv:1507.03126.
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- Edward Farhi, Jeffrey Goldstone, Sam Gutmann. A Quantum Approximate Optimization Algorithm. arXiv:1411.4028
 - Edward Farhi, Aram W Harrow. Quantum Supremacy through the Quantum Approximate Optimization Algorithm. arXiv:1602.07674

4 Quantum Complexity

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5 Quantum Cryptography

1. Device-independent quantum cryptography.

- Robust protocols for securely expanding randomness and distributing keys using untrusted quantum devices by Carl Miller, Yaoyun Shi, STOC 2014. arXiv:1402.0489
- Physical Randomness Extractors: Generating Random Numbers with Minimal Assumptions by Kai-Min Chung, Yaoyun Shi, Xiaodi Wu, QIP 2014. arXiv:1402.4797
- U.V. Vazirani and T. Vidick, "Certifiable Quantum Dice - Or, testable exponential randomness expansion". STOC 2012. arXiv:1111.6054
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- Anand Natarajan, Thomas Vidick. Robust self-testing of many-qubit states. STOC 2017. arXiv:1610.03574.

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- A Note on Quantum Security for Post-Quantum Cryptography by Fang Song, PQCrypto2014. arXiv:1409.2187.
- Using Simon's Algorithm to Attack Symmetric-Key Cryptographic Primitives by Thomas Santoli, Christian Schaffner. arXiv:1603.07856.

6 Quantum Programming Languages

1. Foundations of Quantum Programming Languages.

- Quantum lambda calculus. Book chapter by Benoit Valiron and Peter Selinger. In Simon Gay and Ian Mackie, editors, Semantic Techniques in Quantum Computation, Cambridge University Press, pp. 135–172, 2009.

- Programming the quantum future by Benoit Valiron, Neil J. Ross, Peter Selinger, D. Scott Alexander, and Jonathan M. Smith. *Communications of the ACM* Vol. 58 No. 8, pages 52–61, 2015.
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 - Floyd–hoare logic for quantum programs by Mingsheng Ying. *ACM Transactions on Programming Languages and Systems (TOPLAS)*, Vol 33, Issue 6, pages 16.
2. Simulation, verification, and so on of quantum programs.
- Bisimulation for quantum processes by Yuan Feng, Runyao Duan, and Mingsheng Ying. *POPL*2011.
 - Symbolic bisimulation for quantum processes by Y. Feng, Y. X. Deng, M. S. Ying, *ACM Transactions on Computational Logic*, 15(2) (2014), 14:1-14:32.
 - Model-Checking Linear-Time Properties of Quantum Systems by M. S. Ying, Y. J. Li, N. K. Yu, and Y. Feng. *ACM Transactions on Computational Logic*, 15(3) (2014), 22:1-22:31.
 - Invariants of quantum programs: characterisations and generation by Mingsheng Ying, Shenggang Ying, Xiaodi Wu. *POPL* 2017.
 - QWIRE: A Core Language for Quantum Circuits by Jennifer Paykin, Robert Rand, Steve Zdancewic. *POPL* 2017.

7 Fault-tolerant Quantum Computation

1. Fault-tolerant Quantum Computation.

- D. Aharonov and M. Ben-Or, Fault-Tolerant Quantum Computation with Constant Error Rate. arXiv: quant-ph/9906129
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- D. Gottesman, Fault-Tolerant Quantum Computation with Constant Overhead. arXiv: 1310.2984.
- Earl T. Campbell, Barbara M. Terhal, and Christophe Vuillot. Roads towards fault-tolerant universal quantum computation. *Nature* 549, 172?179.
- Barbara M. Terhal. Quantum Error Correction for Quantum Memories. *Rev. Mod. Phys.* 87, 307 (2015). arXiv:1302.3428.

8 Near-term Quantum Devices

1. Establishing quantum supremacy, in theory or close-to-practical scenarios.

- The Computational Complexity of Linear Optics by S. Aaronson and A. Arkhipov, *Theory of Computing* 4:143-252, 2013. arXiv:1011.3245. (Known as BosonSampling)

- Average-case complexity versus approximate simulation of commuting quantum computations by Michael J. Bremner, Ashley Montanaro, Dan J. Shepherd. QIP 2016. arXiv:1504.07999.
 - Complexity-Theoretic Foundations of Quantum Supremacy Experiments by Scott Aaronson, Lijie Chen, arXiv:1612.05903. (CCC 2017)
 - Quantum computational supremacy by Aram W. Harrow, Ashley Montanaro. Nature 549, 203–209 (14 September 2017).
2. Architecture of quantum hardware.
 - An experimental microarchitecture for a superconducting quantum processor by X. Fu et al. Proceeding MICRO-50 '17 Proceedings of the 50th Annual IEEE/ACM International Symposium on Microarchitecture Pages 813-825. arXiv: 1708.07677.
 - Optimized surface code communication in superconducting quantum computers by A. Javadi-Abhari et al. Proceeding MICRO-50 '17 Proceedings of the 50th Annual IEEE/ACM International Symposium on Microarchitecture Pages 692-705. arXiv:1708.09283.
 - Taming the instruction bandwidth of quantum computers via hardware-managed error correction by S. Tannu. Proceeding MICRO-50 '17 Proceedings of the 50th Annual IEEE/ACM International Symposium on Microarchitecture Pages 679-691.
 3. Better classical algorithms to simulate quantum applications.
 - Classical boson sampling algorithms with superior performance to near-term experiments by A. Neville et al. Nature Physics (2017) arXiv:1705.00686.
 - The Classical Complexity of Boson Sampling by Peter Clifford and Raphael Clifford. SODA 2018. arXiv:1706.01260.

9 Explorative topics

Topics in this section have almost no research result yet. (Please do correct me if I am wrong.)

1. Implement a quantum algorithm with the publicly accessible quantum machines (or simulators), e.g., IBM Q Experience, Microsoft Q#, and so on. Design some measures to compare them.
2. Survey the hardware specifications of publicly accessible quantum machines. Think of any practical method to verify the real quantum machines against their claimed specifications.
3. Please tell me if you have any idea along this line.