Applications of quantum annealing in combinatorial optimization

Yarkoni, S.

Bibliography

[1] Leonhard Euler. Solutio problematis ad geometriam situs pertinentis. *Commentarii academiae scientiarum Petropolitanae*, 8:128–140, 1741.

[2] Carl Hierholzer and Chr Wiener. Ueber die möglichkeit, einen linienzug ohne wiederholung und ohne unterbrechung zu umfahren. *Mathematische Annalen*, 6(1):30–32, March 1873.

[3] Wikipedia. Königsberg — Wikipedia, the free encyclopedia. `http://en.wikipedia.org/w/index.php?title=K%C3%B6nigsberg&oldid=1067675023`, 2022. [Online; accessed 29-January-2022].

[4] Yuri Manin. Computable and uncomputable. *Sovetskoye Radio, Moscow*, 128, 1980.

[5] Paul Benioff. The computer as a physical system: A microscopic quantum mechanical Hamiltonian model of computers as represented by Turing machines. *Journal of Statistical Physics*, 22(5):563–591, 1980.

[6] Paul Benioff. Quantum Mechanical Models of Turing Machines That Dissipate No Energy. *Physical Review Letters*, 48(23):1581–1585, 1982.

[7] Richard P. Feynman. Simulating physics with computers. *International Journal of Theoretical Physics*, 21(6):467–488, 1982.

[8] David Deutsch. Quantum theory, the Church–Turing principle and the universal quantum computer. *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences*, 400(1818):97–117, July 1985.

[9] David Deutsch. Rapid solution of problems by quantum computation. *Proceedings of the Royal Society of London. Series A: Mathematical and Physical Sciences*, 439(1907):553–558, December 1992.

[10] Peter W. Shor. Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer. *SIAM Journal on Computing*, 26(5):1484–1509, October 1997.

[11] Lov K. Grover. A fast quantum mechanical algorithm for database search. In *Proceedings of the Twenty-Eighth Annual ACM Symposium on Theory of Computing*, STOC '96, page 212âĂŞ219, New York, NY, USA, 1996. Association for Computing Machinery.

[12] J. A. Jones and M. Mosca. Implementation of a quantum algorithm on a nuclear magnetic resonance quantum computer. *The Journal of Chemical Physics*, 109(5):1648–1653, August 1998.

[13] Isaac L. Chuang, Lieven M. K. Vandersypen, Xinlan Zhou, Debbie W. Leung, and Seth Lloyd. Experimental realization of a quantum algorithm. *Nature*, 393(6681):143–146, May 1998.

[14] Isaac L. Chuang, Neil Gershenfeld, and Mark Kubinec. Experimental implementation of fast quantum searching. *Phys. Rev. Lett.*, 80:3408–3411, Apr 1998.

[15] Stephan Gulde, Mark Riebe, Gavin P. T. Lancaster, Christoph Becher, Jürgen Eschner, Hartmut Häffner, Ferdinand Schmidt-Kaler, Isaac L. Chuang, and Rainer Blatt. Implementation of the deutsch–jozsa algorithm on an ion-trap quantum computer. *Nature*, 421(6918):48–50, Jan 2003.

[16] J. H. Plantenberg, P. C. de Groot, C. J. P. M. Harmans, and J. E. Mooij. Demonstration of controlled-not quantum gates on a pair of superconducting quantum bits. *Nature*, 447(7146):836–839, Jun 2007.

[17] Florian Dolde, Ville Bergholm, Ya Wang, Ingmar Jakobi, Boris Naydenov, Sébastien Pezzagna, Jan Meijer, Fedor Jelezko, Philipp Neumann, Thomas Schulte-Herbrüggen, Jacob Biamonte, and Jörg Wrachtrup. High-fidelity spin entanglement using optimal control. *Nature Communications*, 5(1):3371, Feb 2014.

[18] R. C. C. Leon, C. H. Yang, J. C. C. Hwang, J. Camirand Lemyre, T. Tanttu, W. Huang, K. W. Chan, K. Y. Tan, F. E. Hudson, K. M. Itoh, A. Morello, A. Laucht, M. Pioro-Ladrière, A. Saraiva, and A. S. Dzurak. Coherent spin control of s-, p-, d- and f-electrons in a silicon quantum dot. *Nature Communications*, 11(1):797, Feb 2020.

[19] Yang Wang, Xianli Zhang, Theodore A. Corcovilos, Aishwarya Kumar, and David S. Weiss. Coherent addressing of individual neutral atoms in a 3d optical lattice. *Phys. Rev. Lett.*, 115:043003, Jul 2015.

[20] Valentin Kasper, Daniel González-Cuadra, Apoorva Hegde, Andy Xia, Alexandre Dauphin, Felix Huber, Eberhard Tiemann, Maciej Lewenstein, Fred Jendrzejewski, and Philipp Hauke. Universal quantum computation and quantum error correction with ultracold atomic mixtures. *Quantum Science and Technology*, 7(1):015008, Nov 2021.

[21] Pascal Scholl, Michael Schuler, Hannah J. Williams, Alexander A. Eberharter, Daniel Barredo, Kai-Niklas Schymik, Vincent Lienhard, Louis-Paul Henry, Thomas C. Lang, Thierry Lahaye, Andreas M. Läuchli, and Antoine Browaeys. Quantum simulation of 2d antiferromagnets with hundreds of rydberg atoms. *Nature*, 595(7866):233–238, Jul 2021.

[22] Z. Vernon, N. Quesada, M. Liscidini, B. Morrison, M. Menotti, K. Tan, and J.E. Sipe. Scalable squeezed-light source for continuous-variable quantum sampling. *Phys. Rev. Applied*, 12:064024, Dec 2019.

[23] Frank Arute, Kunal Arya, Ryan Babbush, Dave Bacon, Joseph C. Bardin, Rami Barends, Rupak Biswas, Sergio Boixo, Fernando G. S. L. Brandao, David A. Buell, Brian Burkett, Yu Chen, Zijun Chen, Ben Chiaro, Roberto Collins, William Courtney, Andrew Dunsworth, Edward Farhi, Brooks Foxen, Austin Fowler, Craig Gidney, Marissa Giustina, Rob Graff, Keith Guerin, Steve Habegger, Matthew P. Harrigan, Michael J. Hartmann, Alan Ho, Markus Hoffmann, Trent Huang, Travis S. Humble, Sergei V. Isakov, Evan Jeffrey, Zhang Jiang, Dvir Kafri, Kostyantyn Kechedzhi, Julian Kelly, Paul V. Klimov, Sergey Knysh, Alexander Korotkov, Fedor Kostritsa, David Landhuis, Mike Lindmark, Erik Lucero, Dmitry Lyakh, Salvatore Mandrà, Jarrod R. McClean, Matthew McEwen, Anthony Megrant, Xiao Mi, Kristel Michielsen, Masoud Mohseni, Josh Mutus, Ofer Naaman, Matthew Neeley, Charles Neill, Murphy Yuezhen Niu, Eric Ostby, Andre Petukhov, John C. Platt, Chris Quintana, Eleanor G. Rieffel, Pedram Roushan, Nicholas C. Rubin, Daniel Sank, Kevin J. Satzinger, Vadim Smelyanskiy, Kevin J. Sung, Matthew D. Trevithick, Amit Vainsencher, Benjamin Villalonga, Theodore White, Z. Jamie Yao, Ping Yeh, Adam Zalcman, Hartmut Neven, and John M.

Martinis. Quantum supremacy using a programmable superconducting processor. *Nature*, 574(7779):505–510, Oct 2019.

[24] Gary J. Mooney, Gregory A. L. White, Charles D. Hill, and Lloyd C. L. Hollenberg. Whole-device entanglement in a 65-qubit superconducting quantum computer. *Advanced Quantum Technologies*, 4(10):2100061, 2021.

[25] M. W. Johnson, M. H. S. Amin, S. Gildert, T. Lanting, F. Hamze, N. Dickson, R. Harris, A. J. Berkley, J. Johansson, P. Bunyk, E. M. Chapple, C. Enderud, J. P. Hilton, K. Karimi, E. Ladizinsky, N. Ladizinsky, T. Oh, I. Perminov, C. Rich, M. C. Thom, E. Tolkacheva, C. J. S. Truncik, S. Uchaikin, J. Wang, B. Wilson, and G. Rose. Quantum annealing with manufactured spins. *Nature*, 473(7346):194–198, 2011.

[26] Trevor Lanting, Andrew D. King, Bram Evert, and Emile Hoskinson. Experimental demonstration of perturbative anticrossing mitigation using nonuniform driver Hamiltonians. *Physical Review A*, 96(4):042322, October 2017.

[27] John Preskill. Quantum Computing in the NISQ era and beyond. *Quantum*, 2:79, August 2018.

[28] Stephen A. Cook. The complexity of theorem-proving procedures. In *Proceedings of the third annual ACM symposium on Theory of computing - STOC '71*. ACM Press, 1971.

[29] Michael A Nielsen and Isaac Chuang. Quantum computation and quantum information, 2002.

[30] IBM. CPLEX optimizer. `https://www.ibm.com/analytics/cplex-optimizer`. [Online; accessed 29-January-2022].

[31] Gurobi Optimization, LLC. Gurobi Optimizer Reference Manual, 2021.

[32] Thomas Bäck. *Evolutionary Algorithms in Theory and Practice*. Oxford University Press, February 1996.

[33] S. Kirkpatrick, C. D. Gelatt, and M. P. Vecchi. Optimization by Simulated Annealing. *Science*, 220(4598):671–680, 1983.

[34] James Kennedy, Russell C. Eberhart, and Yuhui Shi. *Swarm Intelligence*. Elsevier, 2001.

[35] Tadashi Kadowaki and Hidetoshi Nishimori. Quantum annealing in the transverse ising model. *Phys. Rev. E*, 58:5355–5363, Nov 1998.

[36] Edward Farhi, Jeffrey Goldstone, and Sam Gutmann. A Quantum Approximate Optimization Algorithm. *arXiv:1411.4028 [quant-ph]*, November 2014.

[37] Michael Booth, Steven P Reinhardt, and Aidan Roy. Partitioning optimization problems for hybrid classical/quantum execution. *Technical Report*, pages 01–09, 2017.

[38] James King, Masoud Mohseni, William Bernoudy, Alexandre Fréchette, Hossein Sadeghi, Sergei V. Isakov, Hartmut Neven, and Mohammad H. Amin. Quantum-assisted genetic algorithm. *arXiv:1907.00707*, 2019.

[39] Shuntaro Okada, Masayuki Ohzeki, Masayoshi Terabe, and Shinichiro Taguchi. Improving solutions by embedding larger subproblems in a d-wave quantum annealer. *Scientific Reports*, 9(1):2098, 2019.

[40] Edward Farhi, Jeffrey Goldstone, Sam Gutmann, and Michael Sipser. Quantum computation by adiabatic evolution. Technical Report MIT-CTP-2936, preprint available as arXiv:quant-ph/0001106, Center for Theoretical Physics, Massachusetts Institute of Technology, 2000.

[41] Dorit Aharonov, Wim van Dam, Julia Kempe, Zeph Landau, Seth Lloyd, and Oded Regev. Adiabatic quantum computation is equivalent to standard quantum computation. *SIAM Review*, 50(4):755–787, 2008.

[42] Philipp Hauke, Helmut G. Katzgraber, Wolfgang Lechner, Hidetoshi Nishimori, and William D. Oliver. Perspectives of quantum annealing: Methods and implementations. *Reports on Progress in Physics*, 83:054401, March 2020.

[43] Francisco Barahona. On the computational complexity of ising spin glass models. *Journal of Physics A: Mathematical and General*, 15(10):3241, 1982.

[44] Yoshiki Matsuda, Hidetoshi Nishimori, and Helmut G. Katzgraber. Ground-state statistics from annealing algorithms: Quantum versus classical approaches. *New Journal of Physics*, 11(7):073021, July 2009.

[45] Neil G. Dickson and Mohammad H. Amin. Algorithmic approach to adiabatic quantum optimization. *Phys. Rev. A*, 85:032303, Mar 2012.

[46] N. G. Dickson, M. W. Johnson, M. H. Amin, R. Harris, F. Altomare, A. J. Berkley, P. Bunyk, J. Cai, E. M. Chapple, P. Chavez, F. Cioata, T. Cirip, P. deBuen, M. Drew-Brook, C. Enderud, S. Gildert, F. Hamze, J. P. Hilton, E. Hoskinson, K. Karimi, E. Ladizinsky, N. Ladizinsky, T. Lanting, T. Mahon, R. Neufeld, T. Oh, I. Perminov, C. Petroff, A. Przybysz, C. Rich, P. Spear, A. Tcaciuc, M. C. Thom, E. Tolkacheva, S. Uchaikin, J. Wang, A. B. Wilson, Z. Merali, and G. Rose. Thermally assisted quantum annealing of a 16-qubit problem. *Nature Communications*, 4(1):1903, May 2013.

[47] Sebastian Feld, Christoph Roch, Thomas Gabor, Christian Seidel, Florian Neukart, Isabella Galter, Wolfgang Mauerer, and Claudia Linnhoff-Popien. A Hybrid Solution Method for the Capacitated Vehicle Routing Problem Using a Quantum Annealer. *Frontiers in ICT*, 6:13, 2019.

[48] Adam Douglass, Andrew D. King, and Jack Raymond. Constructing SAT Filters with a Quantum Annealer. In Marijn Heule and Sean Weaver, editors, *Theory and Applications of Satisfiability Testing – SAT 2015*, Lecture Notes in Computer Science, pages 104–120, Cham, 2015. Springer International Publishing.

[49] Jie Chen, Tobias Stollenwerk, and Nicholas Chancellor. Performance of domain-wall encoding for quantum annealing. *IEEE Transactions on Quantum Engineering*, 2:1–14, 2021.

[50] R.M. Karp. *Reducibility among combinatorial problems*, volume 85. Complexity of Computer Computations, 1972.

[51] Davide Venturelli, Dominic J. J. Marchand, and Galo Rojo. Quantum Annealing Implementation of Job-Shop Scheduling. *arXiv:1506.08479 [quant-ph]*, 2016.

[52] Eleanor G. Rieffel, Davide Venturelli, Bryan O'Gorman, Minh B. Do, Elicia M. Prystay, and Vadim N. Smelyanskiy. A case study in programming a quantum annealer for hard operational planning problems. *Quantum Information Processing*, 14(1):1–36, January 2015.

[53] Olawale Titiloye and Alan Crispin. Quantum annealing of the graph coloring problem. *Discrete Optimization*, 8(2):376–384, May 2011.

[54] Olawale Titiloye and Alan Crispin. Graph coloring with a distributed hybrid quantum annealing algorithm. In James O'Shea, Ngoc Thanh Nguyen,

Keeley Crockett, Robert J. Howlett, and Lakhmi C. Jain, editors, *Agent and Multi-Agent Systems: Technologies and Applications*, pages 553–562, Berlin, Heidelberg, 2011. Springer Berlin Heidelberg.

[55] Daniel Marx. Graph colouring problems and their applications in scheduling. *Period. Polytech. Electr. Eng.*, 48:11–16, 2004.

[56] Kensuke Tamura, Tatsuhiko Shirai, Hosho Katsura, Shu Tanaka, and Nozomu Togawa. Performance comparison of typical binary-integer encodings in an ising machine. *IEEE Access*, 9:81032–81039, 2021.

[57] S. Karimi and P. Ronagh. Practical integer-to-binary mapping for quantum annealers. *Quantum Inf Process*, 18(94), 2019. preprint arxiv:1706.01945.

[58] David Harris and Sarah Harris. *Digital Design and Computer Architecture.* Elsevier, 2012.

[59] Nicholas Chancellor. Domain wall encoding of discrete variables for quantum annealing and QAOA. *Quantum Science and Technology*, 4(4):045004, August 2019.

[60] Jesse Berwald, Nicholas Chancellor, and Raouf Dridi. Understanding domain-wall encoding theoretically and experimentally. *arXiv:2108.12004*, 2021.

[61] John Golden and Daniel O'Malley. Reverse annealing for nonnegative/binary matrix factorization. *PLOS ONE*, 16(1):e0244026, January 2021.

[62] R. Harris, M. W. Johnson, T. Lanting, A. J. Berkley, J. Johansson, P. Bunyk, E. Tolkacheva, E. Ladizinsky, N. Ladizinsky, T. Oh, F. Cioata, I. Perminov, P. Spear, C. Enderud, C. Rich, S. Uchaikin, M. C. Thom, E. M. Chapple, J. Wang, B. Wilson, M. H. S. Amin, N. Dickson, K. Karimi, B. Macready, C. J. S. Truncik, and G. Rose. Experimental Investigation of an Eight-Qubit Unit Cell in a Superconducting Optimization Processor. *Physical Review B*, 82(2):024511, 2010.

[63] D-Wave System Documentation: QPU-Specific Characteristics. See documents at `https://docs.dwavesys.com/docs/latest/doc_physical_properties.html`, last checked November 2021.

[64] Kelly Boothby, Paul Bunyk, Jack Raymond, and Aidan Roy. Next-generation topology of d-wave quantum processors, 2020.

[65] Reinhard Diestel. *Graph Theory.* Springer.

[66] Vicky Choi. Minor-embedding in adiabatic quantum computation: I. the parameter setting problem. *Quantum Information Processing*, 7(5):193–209, 2008.

[67] Vicky Choi. Minor-embedding in adiabatic quantum computation: II. Minor-universal graph design. *Quantum Information Processing*, 10(3):343–353, June 2011.

[68] Jun Cai, William G. Macready, and Aidan Roy. A practical heuristic for finding graph minors, 2014.

[69] Tomas Boothby, Andrew D. King, and Aidan Roy. Fast clique minor generation in chimera qubit connectivity graphs. *Quantum Information Processing*, 15(1):495–508, 2016.

[70] Davide Venturelli, Salvatore Mandrà, Sergey Knysh, Bryan O'Gorman, Rupak Biswas, and Vadim Smelyanskiy. Quantum optimization of fully connected spin glasses. *Phys. Rev. X*, 5:031040, Sep 2015.

[71] Alexandre M. Zagoskin, Evgeni Ilichev, Miroslav Grajcar, Joseph J. Betouras, and Franco Nori. How to test the "quantumness" of a quantum computer? *arXiv:1401.2870 [quant-ph]*, January 2014.

[72] Troels F. Rønnow, Zhihui Wang, Joshua Job, Sergio Boixo, Sergei V. Isakov, David Wecker, John M. Martinis, Daniel A. Lidar, and Matthias Troyer. Defining and detecting quantum speedup. *Science*, 345(6195):420–424, 2014.

[73] Helmut G. Katzgraber, Firas Hamze, Zheng Zhu, Andrew J. Ochoa, and H. Munoz-Bauza. Seeking quantum speedup through spin glasses: The good, the bad, and the ugly. *Phys. Rev. X*, 5:031026, Sep 2015.

[74] Vasil S. Denchev, Sergio Boixo, Sergei V. Isakov, Nan Ding, Ryan Babbush, Vadim Smelyanskiy, John Martinis, and Hartmut Neven. What is the computational value of finite-range tunneling? *Phys. Rev. X*, 6:031015, Aug 2016.

[75] Jack Raymond, Sheir Yarkoni, and Evgeny Andriyash. Global warming: Temperature estimation in annealers. *Frontiers in ICT*, 3:23, 2016.

[76] James King, Sheir Yarkoni, Mayssam M. Nevisi, Jeremy P. Hilton, and Catherine C. McGeoch. Benchmarking a quantum annealing processor with the time-to-target metric. *arXiv:1508.05087 [quant-ph]*, August 2015.

[77] Andrew Lucas. Ising formulations of many NP problems. *Frontiers in Physics*, 2, 2014.

[78] T. Bäck and S. Khuri. An evolutionary heuristic for the maximum independent set problem. In *Proceedings of the First IEEE Conference on Evolutionary Computation. IEEE World Congress on Computational Intelligence*, pages 531–535 vol.2, 1994.

[79] Yan-Long Fang and P. A. Warburton. Minimizing minor embedding energy: an application in quantum annealing. *Quantum Information Processing*, 19, 2020.

[80] Ravi Boppana and Magnús M. Halldórsson. Approximating maximum independent sets by excluding subgraphs. *BIT*, 32(2):180–196, June 1992.

[81] Jeffrey Marshall, Eleanor G. Rieffel, and Itay Hen. Thermalization, freeze-out, and noise: Deciphering experimental quantum annealers. *Phys. Rev. Applied*, 8:064025, Dec 2017.

[82] D-Wave Systems. Reverse quantum annealing for local refinement of solutions. *D-Wave Whitepaper Series*, 2017.

[83] Yu Yamashiro, Masaki Ohkuwa, Hidetoshi Nishimori, and Daniel A. Lidar. Dynamics of reverse annealing for the fully connected p-spin model. *Phys. Rev. A*, 100:052321, Nov 2019.

[84] Nicholas Chancellor. Modernizing quantum annealing using local searches. *New Journal of Physics*, 19(2):023024, February 2017.

[85] Andrew D. King, Juan Carrasquilla, Jack Raymond, Isil Ozfidan, Evgeny Andriyash, Andrew Berkley, Mauricio Reis, Trevor Lanting, Richard Harris, Fabio Altomare, Kelly Boothby, Paul I. Bunyk, Colin Enderud, Alexandre Fréchette, Emile Hoskinson, Nicolas Ladizinsky, Travis Oh, Gabriel Poulin-Lamarre, Christopher Rich, Yuki Sato, Anatoly Yu. Smirnov, Loren J. Swenson, Mark H. Volkmann, Jed Whittaker, Jason Yao, Eric Ladizinsky, Mark W. Johnson, Jeremy Hilton, and Mohammad H. Amin. Observation of topological phenomena in a programmable lattice of 1,800 qubits. *Nature*, 560(7719):456–460, 2018.

[86] Davide Venturelli and Alexei Kondratyev. Reverse quantum annealing approach to portfolio optimization problems. *Quantum Machine Intelligence*, 1(1-2):17–30, 2019.

[87] Erica Grant, Travis S. Humble, and Benjamin Stump. Benchmarking Quantum Annealing Controls with Portfolio Optimization. *Physical Review Applied*, 15(1):014012, January 2021.

[88] Kazuki Ikeda, Yuma Nakamura, and Travis S. Humble. Application of Quantum Annealing to Nurse Scheduling Problem. *Scientific Reports*, 9(1):12837, September 2019.

[89] Daniele Ottaviani and Alfonso Amendola. Low rank non-negative matrix factorization with d-wave 2000q, 2018.

[90] M. H. S. Amin, Peter J. Love, and C. J. S. Truncik. Thermally Assisted Adiabatic Quantum Computation. *Physical Review Letters*, 100(6):060503, February 2008.

[91] Nicholas Chancellor, Philip J. D. Crowley, Tanja Đurić, Walter Vinci, Mohammad H. Amin, Andrew G. Green, Paul A. Warburton, and Gabriel Aeppli. Disorder-induced entropic potential in a flux qubit quantum annealer. *arXiv:2006.07685 [quant-ph]*, June 2020.

[92] Jeffrey Marshall, Davide Venturelli, Itay Hen, and Eleanor G. Rieffel. Power of pausing: Advancing understanding of thermalization in experimental quantum annealers. *Phys. Rev. Applied*, 11:044083, Apr 2019.

[93] Evgeny Andriyash, Zhengbing Bian, Fabian Chudak, Marshall Drew-Brook, Andrew D. King, William G. Macready, and Aidan Roy. Boosting integer factoring performance via quantum annealing offsets. `https://www.dwavesys.com/resources/publications`, 2016.

[94] Riccardo Mengoni, Daniele Ottaviani, and Paolino Iorio. Breaking rsa security with a low noise d-wave 2000q quantum annealer: Computational times, limitations and prospects. *arXiv:2005.02268*, 2020.

[95] Nikolaus Hansen. The CMA Evolution Strategy: A Comparing Review. In Jose A. Lozano, Pedro Larrañaga, Iñaki Inza, and Endika Bengoetxea, editors, *Towards a New Evolutionary Computation: Advances in the Estimation of*

Distribution Algorithms, pages 75–102. Springer Berlin Heidelberg, Berlin, Heidelberg, 2006.

[96] Christian Igel, Thorsten Suttorp, and Nikolaus Hansen. A Computational Efficient Covariance Matrix Update and a (1+1)-CMA for Evolution Strategies. In *Proceedings of the 8th Annual Conference on Genetic and Evolutionary Computation*, GECCO '06, pages 453–460, New York, NY, USA, 2006. ACM.

[97] Anne Auger and Nikolaus Hansen. Benchmarking the (1+1)-CMA-ES on the BBOB-2009 Noisy Testbed. In *Proceedings of the 11th Annual Conference Companion on Genetic and Evolutionary Computation Conference: Late Breaking Papers*, GECCO '09, pages 2467–2472, New York, NY, USA, 2009. ACM.

[98] Florian Neukart, Gabriele Compostella, Christian Seidel, David von Dollen, Sheir Yarkoni, and Bob Parney. Traffic flow optimization using a quantum annealer. *Frontiers in ICT*, 4:29, 2017.

[99] D-Wave Systems has produced an open-source software stack in Python (Ocean tools) for accessing its quantum hardware, formulating problems for execution, and classical QUBO/Ising solvers. More information can be found at `https://docs.ocean.dwavesys.com/en/stable/`, last checked november 2021.

[100] Fred W. Glover and Manuel Laguna. *Tabu Search*. Springer US, 1997.

[101] Clark Alexander, Luke Shi, and Sofya Akhmametyeva. Using quantum mechanics to cluster time series. *arXiv*, 2018.

[102] Esma Aimeur, Gilles Brassard, and SÃľbastien Gambs. Quantum speed-up for unsupervised learning. *Machine Learning*, 90:261–287, 02 2013.

[103] Nathan Wiebe, Ashish Kapoor, and Krysta Svore. Quantum algorithms for nearest-neighbor methods for supervised and unsupervised learning. *Quantum Information and Computation*, 15:318–358, 03 2015.

[104] David Horn and Assaf Gottlieb. The method of quantum clustering. In *Proceedings of the 14th International Conference on Neural Information Processing Systems: Natural and Synthetic*, NIPS '01, page 769âĂŞ776, Cambridge, MA, USA, 2001. MIT Press.

[105] Vaibhaw Kumar, Gideon Bass, Casey Tomlin, and Joseph Dulny. Quantum annealing for combinatorial clustering. *Quantum Information Processing*, 17(2):39, 2018.

[106] Florian Neukart, David Von Dollen, and Christian Seidel. Quantum-assisted cluster analysis on a quantum annealing device. *Frontiers in Physics*, 6:55, 2018.

[107] Kazuo Iwama, Junichi Teruyama, and Shuntaro Tsuyama. Reconstructing strings from substrings: Optimal randomized and average-case algorithms. *ArXiv*, 1808.00674, 2018.

[108] Jayadev Acharya, Hirakendu Das, Olgica Milenkovic, Alon Orlitsky, and Shengjun Pan. On reconstructing a string from its substring compositions. pages 1238 – 1242, 07 2010.

[109] Alan M Frieze, Franco P Preparata, and Eli Upfal. Optimal reconstruction of a sequence from its probes. *Journal of Computational Biology*, 6(3-4):361–368, 1999.

[110] Steven S Skiena and Gopalakrishnan Sundaram. Reconstructing strings from substrings. *Journal of Computational Biology*, 2(2):333–353, 1995.

[111] Patrick Schäfer and Mikael Högqvist. Sfa: a symbolic fourier approximation and index for similarity search in high dimensional datasets. In *Proceedings of the 15th International Conference on Extending Database Technology*, pages 516–527. ACM, 2012.

[112] Jon Hills, Jason Lines, Edgaras Baranauskas, James Mapp, and Anthony Bagnall. Classification of time series by shapelet transformation. *Data Mining and Knowledge Discovery*, 28(4):851–881, 2014.

[113] Anthony Bagnall, Jason Lines, Aaron Bostrom, James Large, and Eamonn Keogh. The great time series classification bake off: a review and experimental evaluation of recent algorithmic advances. *Data Mining and Knowledge Discovery*, 31(3):606–660, May 2017.

[114] Anthony Bagnall, Jason Lines, William Vickers, and Eamonn Keogh. The uea & ucr time series classification repository. `www.timeseriesclassification.com`. Accessed: 2020-02-01.

[115] Abdullah Mueen, Eamonn Keogh, and Neal Young. Logical-shapelets: an expressive primitive for time series classification. In *Proceedings of the 17th ACM SIGKDD international conference on Knowledge discovery and data mining*, pages 1154–1162. ACM, 2011.

[116] Chotirat (Ann) Ratanamahatana and Eamonn J. Keogh. Three myths about dynamic time warping data mining. In Hillol Kargupta, Jaideep Srivastava, Chandrika Kamath, and Arnold Goodman, editors, *SDM*, pages 506–510. SIAM, 2005.

[117] Goldberger AL, Amaral LAN, Glass L, Ivanov JM, Hausdorff amd PCh, Mark RG, Mietus JE, GB Moody, Peng C-K, and HE Stanley. Mit-bih long-term ecg database. `physionet.org/content/ltdb/1.0.0/`. PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Resource for Complex Physiologic Signals (2003). Circulation. 101(23):e215-e220.

[118] Patrick Wagner, Nils Strodthoff, Ralf-Dieter Bousseljot, Dieter Kreiseler, Fatima I. Lunze, Wojciech Samek, and Tobias Schaeffter. Ptb-xl, a large publicly available electrocardiography dataset. *Scientific Data*, 7(1):154, May 2020.

[119] Dau H.A. Chinatown. `http://www.pedestrian.melbourne.vic.gov.au`. Accessed: 2020-02-01.

[120] H. Sakoe and S. Chiba. Dynamic programming algorithm optimization for spoken word recognition. *IEEE Transactions on Acoustics, Speech, and Signal Processing*, 26(1):43–49, 1978.

[121] European Commission. Clean transport, urban transport. `https://ec.europa.eu/transport/themes/urban/urban_mobility_en`.

[122] Sasan Amini, Eftychios Papapanagiotou, and Fritz Busch. *Traffic Management for Major Events*, pages 187–197. 07 2016.

[123] Julia Lindner. Big-data-analysen für verkehr in münchen. https://www.telefonica.de/news/corporate/2017/08/kooperation-von-telefonica-next-und-intraplan-big-data-analysen-fuer-verkehr-in-muenchen.html.

[124] Mapbox. Image uses map data from mapbox and openstreetmap and their data sources. to learn more, visit https://www.mapbox.com/about/maps/ and http://www.openstreetmap.org/copyright.

[125] T. Epping, W. Hochstättler, and P. Oertel. Complexity results on a paint shop problem. *Discrete Applied Mathematics*, 136(2):217–226, 2004. The 1st Cologne-Twente Workshop on Graphs and Combinatorial Optimization.

[126] P. Bonsma, T. Epping, and W. Hochstättler. Complexity results on restricted instances of a paint shop problem for words. *Discrete Appl. Math.*, 154(9):1335–1343, June 2006.

[127] M. Streif, S. Yarkoni, A. Skolik, F. Neukart, and M. Leib. Beating classical heuristics for the binary paint shop problem with the quantum approximate optimization algorithm. *Phys. Rev. A*, 104:012403, Jul 2021.

[128] Tamás Kis. On the complexity of the car sequencing problem. *Operations Research Letters*, 32(4):331–335, 2004.