Research on automatic reorganization of digital puzzle based on annealing algorithm

Ruei-Wei Le(李睿緯)[1*] ,Huei-Ru Fuh(傅薈如)[1**]

[1] 元智大學化學工程與材料科學學系

*email:s1135202@mail.yzu.edu.tw **email:hrfuh@saturn.yzu.edu.tw

This research utilizes quantum annealing [1][2] to solve the combinatorial optimization problem of puzzle solving. Traditional computers commonly employ Monte Carlo tree search [3], Genetic Algorithms [4], and Greedy Algorithms [5] to address combinatorial optimization problems. However, these methods take high computational and algorithmic design costs, making them ineffective when dealing with high-complexity problems. Quantum computers are currently considered to have enormous potential for solving problems that are difficult to address with classical computers, with quantum annealing specifically designed to tackle combinatorial optimization problems. When using quantum annealing, we need to transform the problem into a Hamiltonian, with two models available: QUBO [6] and the Ising model [7], where the minimum value of the model corresponds to the optimal solution of the problem.

In this study, we computed both Color Reconstruction Problems (CRP) and Edge Reconstruction Problems (ERP), calculating puzzles ranging from 3×3 to 10×10 in size, using both D-wave Hybrid and D-wave Simulated Annealing for comparison. This research compares the results and discusses their practicality, enabling quantum annealing to serve as one of the computational method options for future combinatorial optimization problems similar to puzzle solving.

Reference

[1] A.B. Finnila, M.A. Gomez, C. Sebenik, C. Stenson, J.D. Doll.(1994), Quantum annealing: A new method for minimizing multidimensional functions, Chemical Physics Letters, Volume 219, Issue 5, p. 343-348.

[2] Dulundu, Alp. (2024). Revolutionizing Optimization: The Game-Changing Power of Quantum Algorithms and Next-Generation Computational Technologies, Next Frontier For Life Sciences and AI. 8. 51. 10.62802/9tacw830.

[3] Paumard, Marie-Morgane & Tabia, Hedi & Picard, David. (2023). Alphazzle: Jigsaw Puzzle Solver with Deep Monte-Carlo Tree Search. 10.48550/arXiv.2302.00384.

[4] Guo, Wenjing & Wei, Wenhong & Zhang, Yuhui & Fu, Anbing. (2020). A Genetic Algorithm-Based Solver for Small-Scale Jigsaw Puzzles. 10.1007/978-3-030-53956-6_32.

[5] Utsunomiya, Kaede & Asahiro, Yuichi. (2017). Improvement of the greedy algorithm for (n2 - 1)-puzzle. International Journal of Innovative Computing and Applications. 8. 133. 10.1504/IJICA.2017.086632.

[6] M. Zaman, K. Tanahashi and S. Tanaka(2022), "PyQUBO: Python Library for Mapping Combinatorial Optimization Problems to QUBO Form," in *IEEE Transactions on Computers*, vol. 71, no. 4, pp. 838-850, doi: 10.1109/TC.2021.3063618.

[7] Cipra, B. A. (1987). An Introduction to the Ising Model. *The American Mathematical Monthly*, *94*(10), 937–959. https://doi.org/10.1080/00029890.1987.12000742