

A machine learning approach that beats Rubik's cubes

ML-heuristic pathfinder for general Cayley graphs

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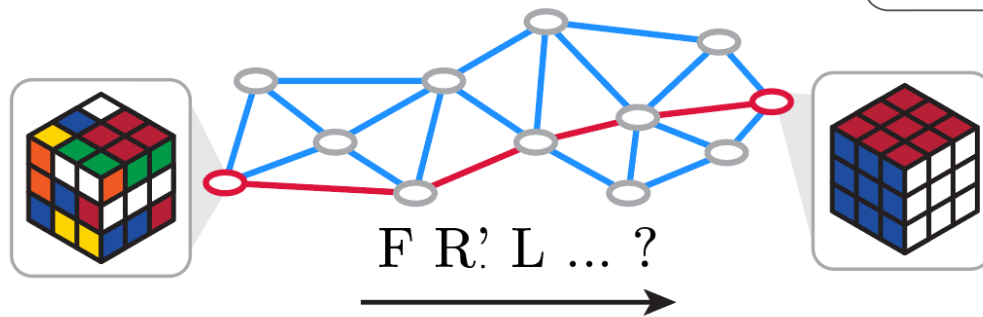
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Problem & Scale

- It was demonstrated $\approx 70\%$ optimality solving $3\times 3\times 3$ Rubik's cube with ML approaches [1,2]
- In 2023, over 1000 teams competed in a Kaggle challenge [3] solving $3\times 3\times 3$, $4\times 4\times 4$, $5\times 5\times 5$ and other general Cayley graphs
- Solving the Rubik's Cube Optimally is NP-complete [4]

The number of $5\times 5\times 5$ Rubik's cube's states is comparable to the number of atoms in the universe.



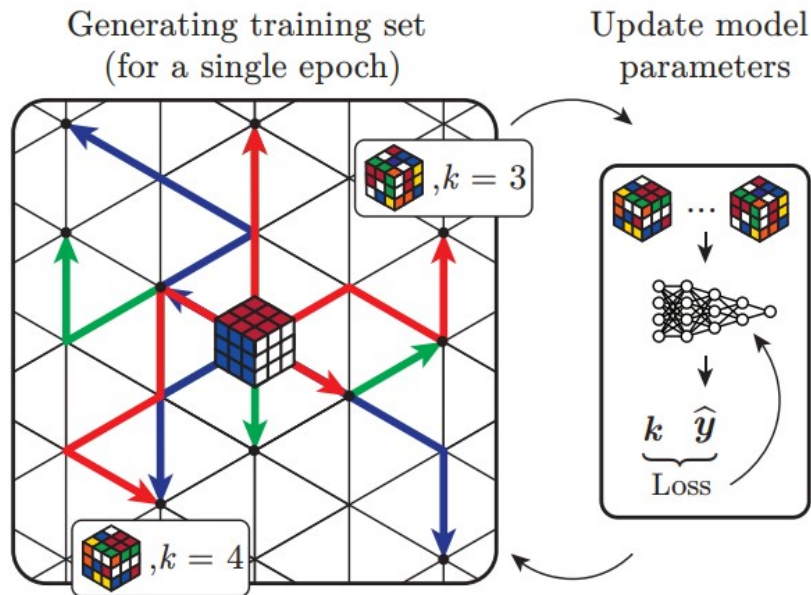
[1] Agostinelli et al. Solving the Rubik's cube with deep reinforcement learning and search. Nat Mach Intell 1, 356–363 (2019)

[2] Takano. Self-Supervision is All You Need for Solving Rubik's Cube. TMLR (2025)

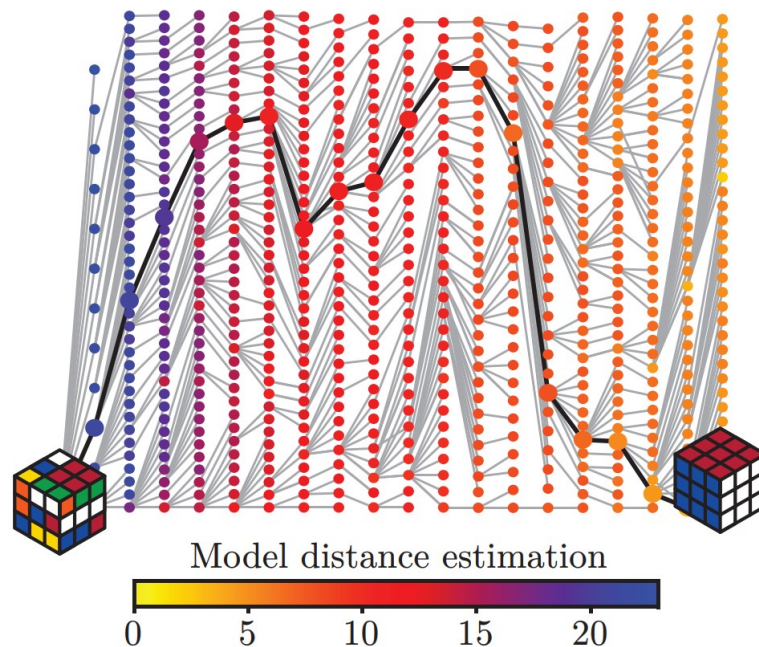
[3] Kaggle. Santa 2023 – The Polytope Permutation Puzzle. Kaggle (2023)

[4] Demaine et al. Solving the Rubik's Cube Optimally is NP-complete. STACS (LIPIcs) 96, 24:1–24:13 (2018)

Method: Train with Random Walks

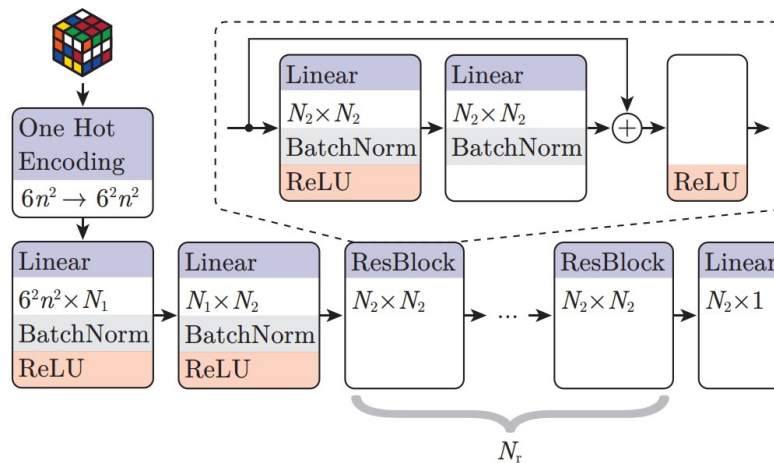
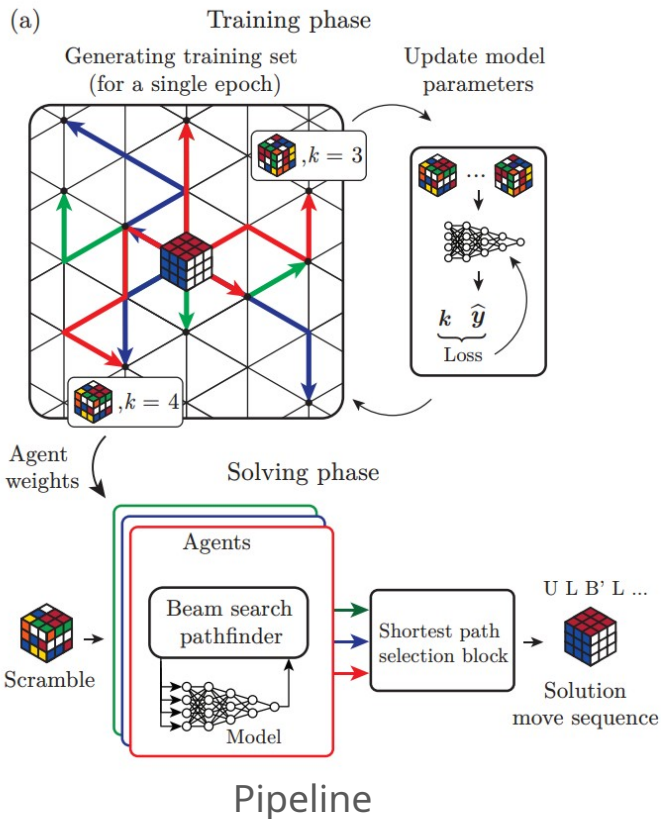


Training phase

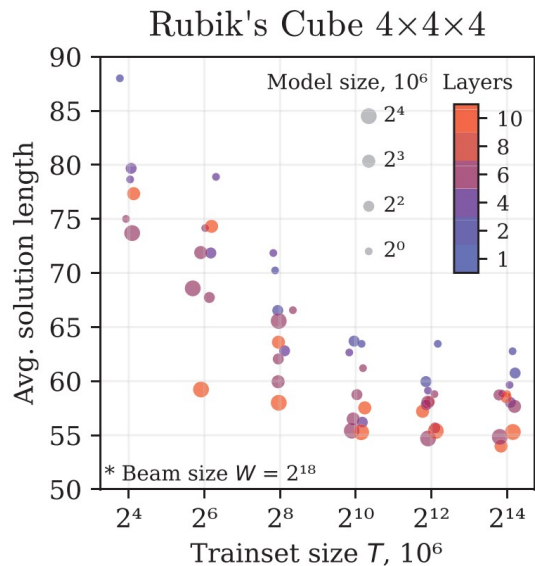


Solving phase

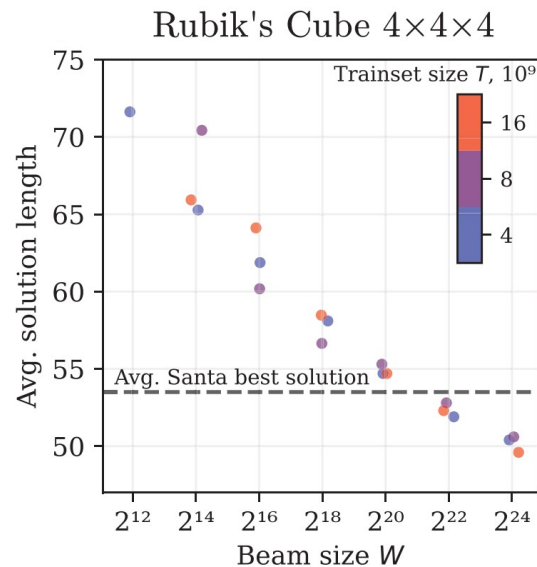
Method: Train with Random Walks



Scaling Effects: Model & Dataset Size



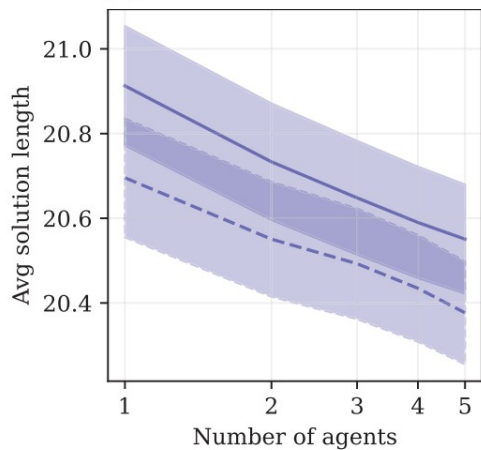
Model can be smaller
Train phase can be shorter



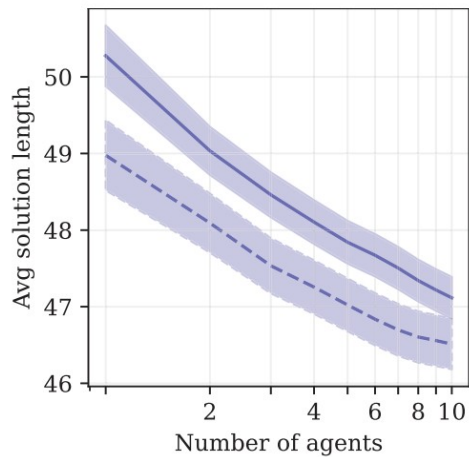
Larger beam \Rightarrow shorter solution

Train & Solve in Parallel

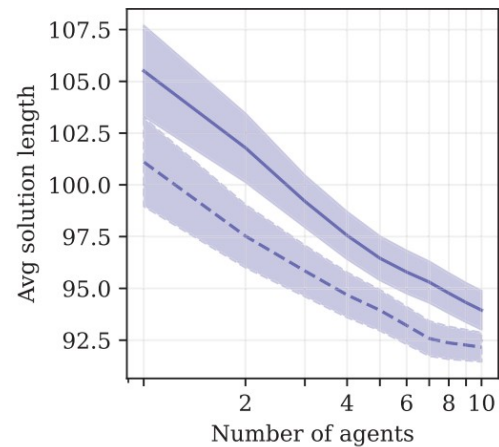
(a) Rubik's Cube $3 \times 3 \times 3$



(b) Rubik's Cube $4 \times 4 \times 4$



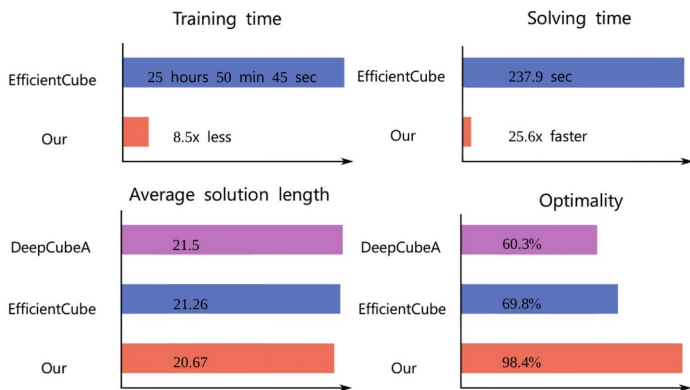
(c) Rubik's Cube $5 \times 5 \times 5$



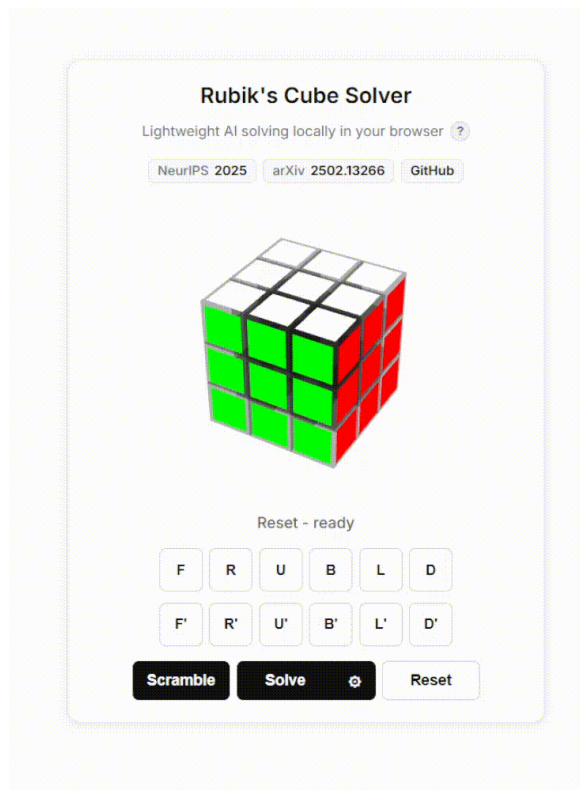
solid line - random set
dashed line - best set

Results

- Faster and shorter solutions



- Can be run directly in browser (.js)
- Beat all 2023 Kaggle Santa Challenge solutions up to 5×5×5 Rubik's cube
- Solved a broad range of puzzles represented by Cayley graphs of size up to 10^{145}



Code (git)



Demo