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MAKING A LIMITED ROBOT SOLVE THE MAGIC CUBE

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Objectives

The Rubik's Cube is the best-selling toy ever, with 350 million copies sold since 1974. With so many years on the market, thousands of people have tried to unravel the secrets of its composition. With over 43 quintillion possible configurations, it is considered one of the most complex toys ever created.

Several people have dedicated time to solving the Rubik's Cube, both in terms of the number of moves and the time taken to solve it. Currently, the world record is 3.83 seconds, with an average of 40 to 50 moves. However, this is the human record; a computer is capable of solving it in less than 20 moves, according to God Number's theorem [1].

Using these algorithms to solve the scrambled cube, several robots have been created that are capable of performing these moves as quickly as possible, which is not the focus of this project. A robot widely used for teaching the magic cube is the *GAN Robot,* a robot similar to the others, but with one less axis, which makes it impossible to execute conventional algorithms on it. Therefore, the objective of this work is to use existing algorithms as a basis and be able to create one that solves the problem with any combination of axes that the user has.

Figure 1: GanRobot with the upper axis missing

Methodology

The main methodology used was the *meet-in-the-middle* concept, a type of algorithm used in large graphs. Instead of applying conventional algorithms to a node to find the destination, two algorithms are used, one at the destination and one at the origin.

This approach brings several problems, such as having to store all the nodes of the two graphs and compare them with each other, which can be solved with a *hashmap*, used to know if a node is in the other graph instantly, without having to check all the nodes.

The base algorithm used was Kociemba ([2]), a well-established algorithm in academia, but designed only for robots that have all axes. Using the concept of this algorithm as a basis, and *meet in the middle* to execute it, it is possible to recreate the Kociemba algorithm for any and all axis combinations.

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The way to do this is, when expanding the graph with *meet in the middle*, to choose only the movements that users allow, making it possible to prove that not all axes are necessary to solve the cube, and furthermore, to disseminate the Kociemba algorithm.

As we know, the *God Number* is 20 moves, so each *meet-in-the-middle* algorithm should expand 10 times, which, although not 43 quintillion cubes, is still an unfeasible number for any modern computer. The solution to this is to first solve the orientation of the cube and then, using meet-in-the-middle, restrict the possible moves so that when the algorithm expands, it finds the solution in a feasible space. The image below shows what an oriented cube looks like.

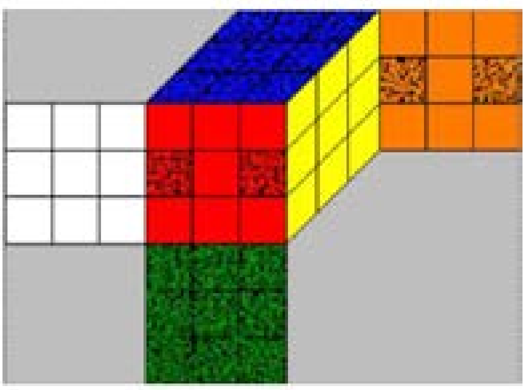

Figure 2: Oriented Cube

After the shaded faces of the magic cube are as shown in the image above, regardless of the rest, we say that it is oriented, that is, to solve it, we only need the movements ¡U, D, R2, L2, F2, B2¿, which reduces our search space and makes the algorithm feasible.

Results

Implementing the algorithm described above, we can verify the results below in the two images:

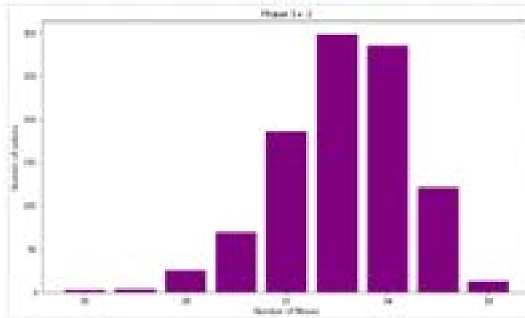

Figure 3: Number of moves to solve with all available moves

```
Phase 1 + 2
Mean:  22.165368
Max:  116.86
Min:  0.418000000
```

Figure 4: Time in seconds it took to run the simulations with all available movements.

Now, removing one of the axes to test the theory described in the methodology, we have the results below:

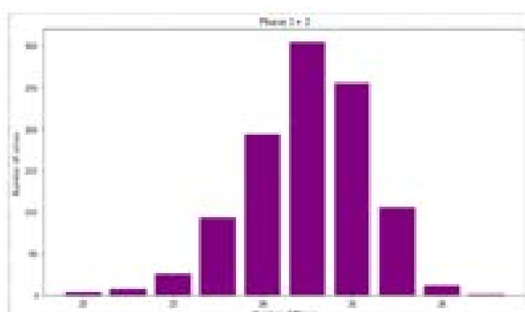

Figure 5: Number of movements required to solve with one axis removed

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Phase 1 + 2
Mean:  20.973677
Max:  237.031
Min:  1.532
```

Figure 6: Time in seconds it took to run the simulations with one axis removed

Conclusion

It can be concluded from this summary that the results were achieved, the cubes can be solved in a timely manner, with a number very close to the God Number, both with all available moves and by removing one axis, showing that there is still research to be done in the area, such as how many minimum axes are needed to solve it? What is the God Number for these cases, etc.?

Reference

[1] Rokicki, Tomas; Kociemba, Herbert; Davidson, Morley; Dethridge, John (2010). “God’s Number is 20”. Cube20.org. Retrieved March 15, 2022.

[2] Kociemba Herbert, WebSite http://kociemba.org/cube.htm

[3] Jaap Scherphuis, que inspirou WebSite, método que inspirou O kociemba https://www.jaapsch.net/puzzles/puzzlink.htm