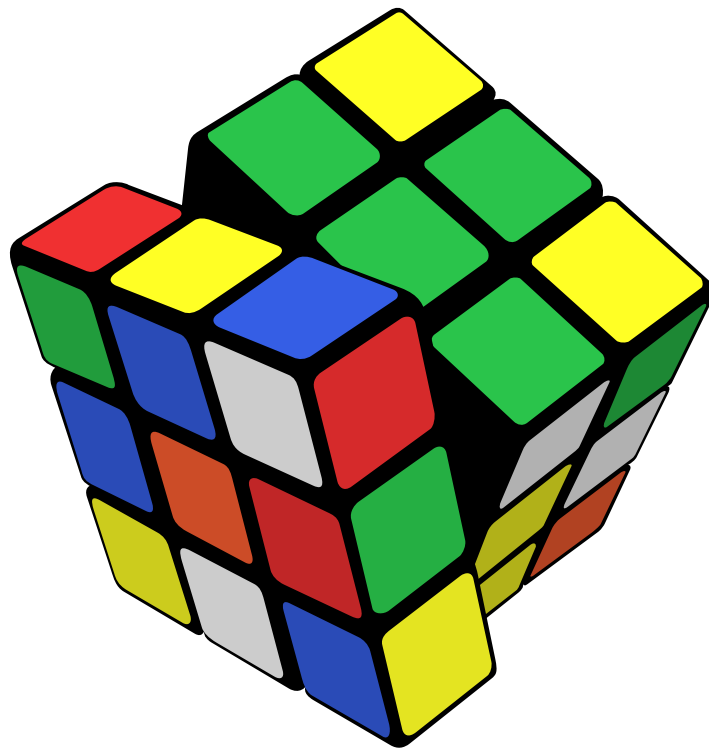


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# Rubik's Cube

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## OWNER'S MANUAL

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24<sup>th</sup> October, 2013

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# 1 Introduction

The Rubik's Cube is a three-dimensional tactile and visual puzzle contained within a  $3 \times 3 \times 3$  cube. Each face of the cube can be swivelled independently; the goal of the puzzle is to find a pattern of rotations that leads to a cube where each face is of a uniform, distinct colour. The puzzle tests spatial awareness, visual perception, and dexterity.

It was invented by Hungarian professor of architecture Ernő Rubik in 1974; at the time, Rubik was trying to create an object that could stay intact even as its parts were allowed to move freely. When, after scrambling the object he had made, he found that he could not easily restore its original configuration, he realised its potential as an intriguing puzzle. It was originally patented and marketed as the 'Magic Cube' (Bűvös kocka) in Hungary; however, after failing to secure an international patent, Rubik renamed it the 'Rubik's Cube', in order to gain at least a recognisable name to trademark.



Figure 1: Ernő Rubik with his creation

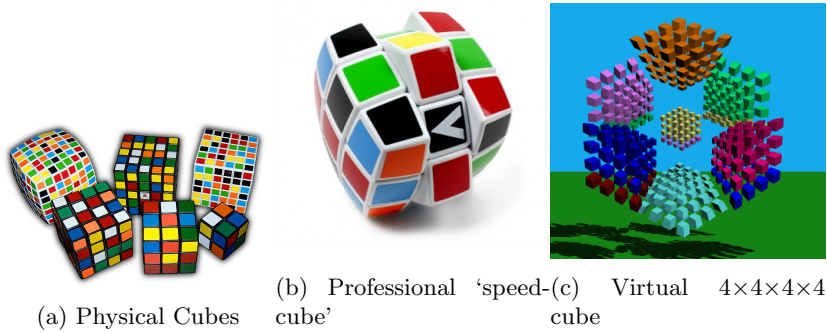


Figure 2: Cube variants

An instant hit in the West, the cube became an icon of the '80s, inspiring a number of contests and clubs. It also spun-off a number of derivative puzzles, from the  $4 \times 4 \times 4$  'Rubik's Revenge' to the  $17 \times 17 \times 17$  'Over The Top'. Further, computer modelling has allowed enthusiasts to play with variants that would be impractical (hundreds or thousands of cubelets) or even impossible (higher-dimension cubes) to build in real life.

The standard cube is composed of 26 pieces, also called 'cubelets':

**6 Centre Pieces** These pieces are at the centres of the cube faces. They feature one colour each. As can be seen in Figure 3, these pieces are always stationary relative to one another.

**12 Edge Pieces** Edge pieces are located in between two centre faces. They have two colours each, which determine the final position of the piece<sup>1</sup>. These rotate around the centres.

**8 Corner Pieces** These are located at the corners of the cube, and have three colours each. As with edge pieces, these colours determine the final position of the piece<sup>2</sup>.

This gives a total of  $6 \times 1 + 12 \times 2 + 8 \times 3 = 9 \times 6 = 54$  facelets.



Figure 3: Cutaway Diagram

<sup>1</sup>For example, in Figure 3, the blue-orange edge would go between the blue and orange centres. Since blue and green are opposite to each other, there is no blue-green edge.

<sup>2</sup>The blue-orange-yellow corner goes between the blue, orange and yellow edges. There is no blue-orange green corner.

## 2 Description

### 2.1 Overall Description

**Dimensions** 57 mm  $\times$  57 mm  $\times$  57 mm

**Weight** 100 g

**Material** Hard plastic

**Appearance** Black; individual facelets are coated by a brightly coloured sticker to differentiate the faces.

### 2.2 Description of Parts

#### 2.2.1 Central Core

The central 3D cross holds the cube together. It has a yoke (see Figure 4a), along which are attached the six centre facelets (see Figure 4b). The resultant part is shown in Figure 4c.

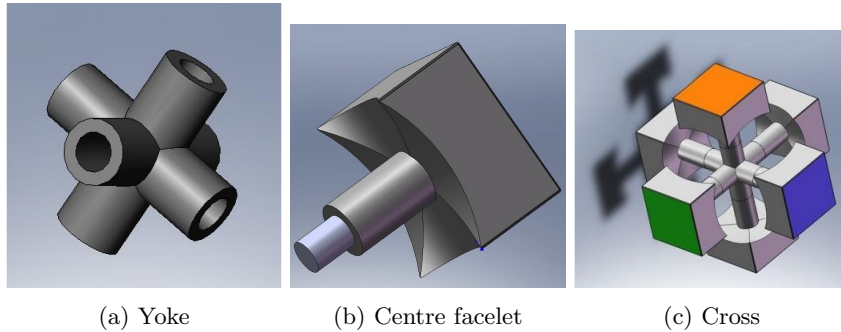


Figure 4: Core

#### 2.2.2 Exterior Facelets

Surrounding the cross described in 2.2.1 are edge(Figure 5a) and corner(Figure 5b) cubelets, with two and three facelets respectively. They feature extrusions that lock them to the core, while still allowing them to be manipulated easily.

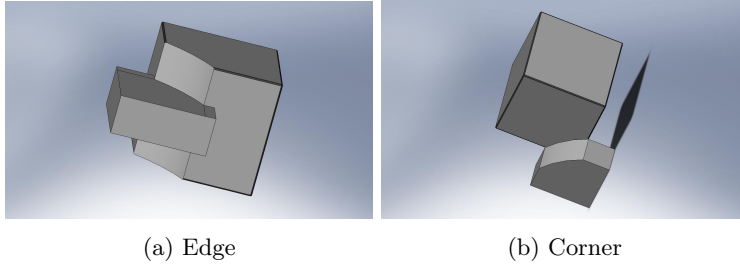


Figure 5: Exterior facelets

### 3 Assembly

Assembly of a dismantled cube requires the following steps:

1. Centre facelets are attached to the yolk via rivets to create the core ( 2.2.1).
2. Corner cubelets are locked in place via their extrusions.
3. Edge pieces are locked in.
4. Steps (2) and (3) are repeated layer-wise until the cube is complete.

This process is shown in Figure 6.

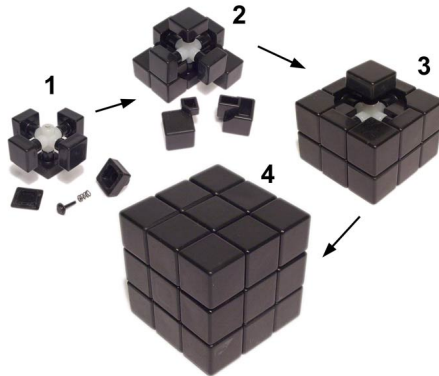


Figure 6: Assembly

## 4 Process

This section presents the ‘Layer Method’ for solving the cube. This algorithm is far from optimal, but is easy for beginners to learn. We shall start with the white face for this example; in general, one can start from any face.

**Matters of notation** This section utilises standard Rubik’s Cube notation to describe the solution. Consult Appendix A for information on this notation.

### 4.1 Cross

This first step requires correctly placing any edge with white; this completes the ‘cross’ on the white face and aligns the edges appropriately. This results in the configuration shown in Figure 7.

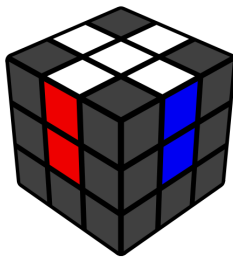
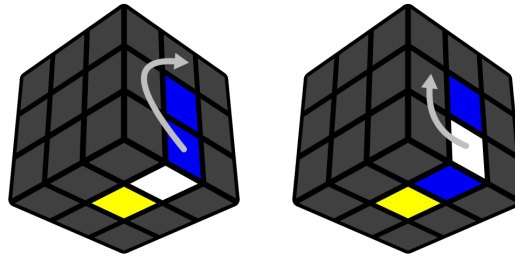


Figure 7: Solved white cross

1. Find a white edge piece on the bottom layer.
2. Twist the bottom layer to align the piece you found with the corresponding non-white centre.
3. Bring the piece to the top layer:
  - (a) If the edge is already correctly aligned with the centre, twist it  $180^\circ$ , as seen in Figure 8a.
  - (b) Otherwise, twist it  $90^\circ$  to move it to the middle layer on a different face. Twist that new face to bring it back to the bottom layer. Then, go back to step 2. This is shown in Figure 8b.



(a) If aligned

(b) If not aligned

Figure 8: Bringing edges up

4. Repeat from step 1 until there are no more white edges on the bottom layer.
5. Bring any white edges on the middle layer to the bottom layer by twisting  $90^\circ$ .
6. Repeat from step 1 until there are no more white edges on the middle layer.
7. Bring *unsolved* white edges to the bottom layer by twisting  $180^\circ$ .
8. Repeat from step 1 until the cross is complete.



## 4.2 Corners

In this section, we correctly place corners. This completely solves the top layer as shown in Figure 9.

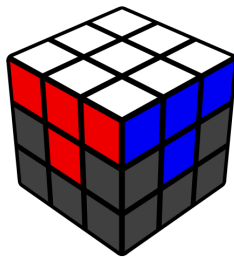


Figure 9: Solved top layer

1. Find an unsolved corner piece and bring it to the bottom layer.
2. Twist the bottom layer to bring it underneath where it is supposed to go. It will then be in one of the configurations shown in Figure 10.

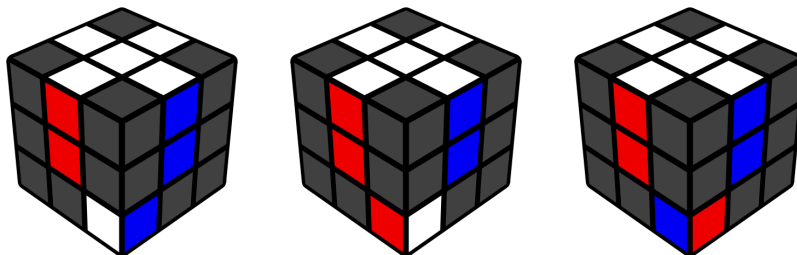


Figure 10: Possible configurations of the corner piece.

3. Hold the cube so that the corner appears at the bottom-right of the front face.
4. Perform the algorithm  $R'D'RD$  repeatedly until the corner is solved.
5. Repeat from step 1 until all corners are solved.

### 4.3 Middle Layer

This section solves the middle layer to arrive at Figure 11.

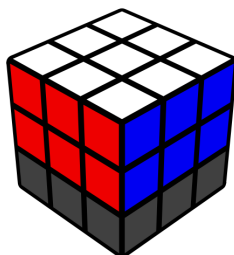


Figure 11: Solved middle layer

1. Flip the cube so that the white face is on the bottom. This allows you to observe the bottom (now top) layer easily.
2. Find an edge on the new top layer that belongs in the middle layer.
3. Align the side of that edge with the corresponding centre on the middle layer.
4. The top face of the edge will be in one of the following configurations. Holding the edge in front of you, perform the appropriate algorithm:
  - (a) Matches the left centre (as in Figure 12a); do  $U'L'ULUFU'F'$ .
  - (b) Matches the right centre (as in Figure 12b); do  $URU'R'U'F'UF$ .



(a) Matches left



(b) Matches right

Figure 12: Possible configurations of the middle edge.

5. Repeat from step 1 until the middle layer is done.
6. Flip the cube back to white on top.

## 4.4 Bottom Cross

The general strategy for this stage is:

1. Make a (not necessarily aligned) cross, see Figure 13a.
2. 'Fix' the cross, see Figure 13b.

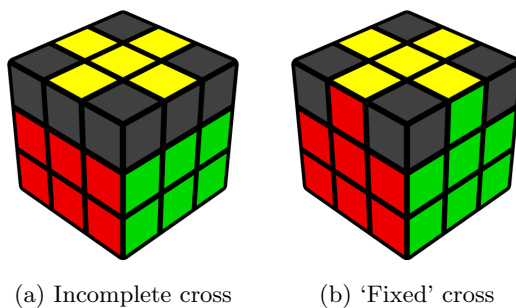


Figure 13: Bottom cross

1. Flip the white face back to the bottom.
2. Repeat  $FRUR'U'F'$  until a cross appears on the yellow face.
3. Twist the yellow face to fix the cross.
4. If only two yellow edges can be fixed, there are two cases:
  - (a) The fixed edges are opposite. In this case, hold the cube such that any one of the fixed yellow edges is in front of you, then do  $RUR'URU2R'$ . This puts you in the next case.
  - (b) The fixed edges are adjacent. In this case, do  $RUR'URU2R'$ . This fixes all edges to complete the stage.
5. Flip the white face back up and ensure that none of the previous moves have been disturbed.

## 4.5 Final Layer

As with stage 4.4, there are two parts to this stage:

1. Position the corners correctly, see Figure 14a.
2. Align the corners, see Figure 14b.

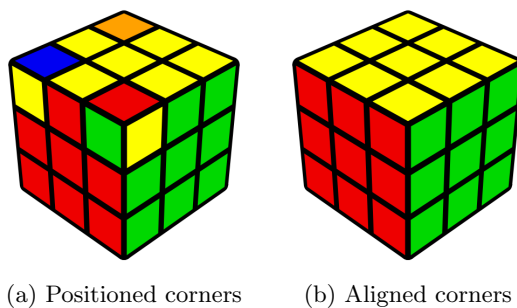


Figure 14: Bottom corners

1. Flip the white face to the bottom.
2. Choose a corner that is already in the correct position. If no such corner is available:
  - (a) Looking at any face of the cube, do  $URU'L'UR'U'L$ .
  - (b) Repeat step 2a until at least one corner is fixed.
  - (c) Choose a fixed corner and proceed.
3. Orient the cube so that the chosen corner is on the top-right of the front face.
4. Do  $URU'L'UR'U'L$  until all corners are fixed.
5. Repeat  $R'D'RD$  until the top-right corner is correctly aligned.
6. Rotate the entire cube  $90^\circ$  to the left. Repeat step 5.
7. Repeat step 6 until all corners are aligned.
8. Twist the middle layer until the cube is solved.

## 5 Conclusion

The standard Rubik's Cube remains the world's best-ever selling toy, with over 350 million units sold to date. Perhaps it is past the height of its popularity, yet interest in the cube has endured as mathematicians continue to look for an optimal solution to the puzzle. An enthusiastic 'speedcubing' community continues solving the cube ever faster, with the world record currently at 5.55 seconds.

For more information about the Rubik's cube, including purchases, additional puzzles, community interaction and more, consult the official website at <http://www.rubiks.com>.

## A Algorithm Notation

The Rubik's Cube community has developed a standardised notation to efficiently represent moves. Each face of the cube is assigned a letter, and rotations of faces are represented by their corresponding letters followed by some modifiers.

- A single letter (Eg. F) means the face must be turned clockwise by  $90^\circ$ .
- A letter followed by a prime (Eg. R') means the face must be turned *counter*-clockwise by  $90^\circ$ .
- A letter followed by '2' (Eg. U2) means the face should be turned  $180^\circ$ . In this case, the direction of rotation does not matter.

Note that these moves are always relative to the face that the solver is looking at; see Figure 15. These individual moves can be concatenated to produce move

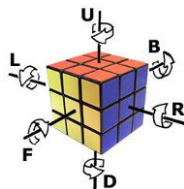


Figure 15: Move notation

sequences, such as the very commonly used 'corner algorithm',  $R'D'RD$ .

## References

- [1] Toby Heavenrich and Pierre Dyer. Rubik's cube project. [http://wikis.swarthmore.edu/ENGR005\\_2008/index.php/Rubik%27s\\_Cube#E5\\_Links](http://wikis.swarthmore.edu/ENGR005_2008/index.php/Rubik%27s_Cube#E5_Links).
- [2] Conrad Rider. Visualcube. <http://cube.crider.co.uk/visualcube.php>.