Rubik's Cube & the Sun

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Rubik's Cube Tutorial

1 Prerequisites

To solve the traditional 3x3x3 Rubiks Cube, let's first cover some basics. There are 3 different types of pieces which can be found on the cube: A center piece, an edge piece and a corner piece. You can separate them by counting how many different colors they have. A center piece has only one color and is immovable. Therefore, these pieces will determine the color of the face once it is solved. The edge pieces have stickers of two colors on them, and the corner pieces have three different color stickers on them. Here comes the first important fact about these pieces: You can never change the location of a certain type of piece with a different type of piece! For example, you cannot swap a corner piece, with an edge or center piece.

The last thing before we get started is the notation. I will be using pictures to help following along, but typically in many online resources, people will only use the standard notation to tell you which turns you should make to solve a certain case. There are 6 elementary turns (plus their inverse) that one can do, each noted by a singular letter (and adding a ' symbol for the inverse) as shown in **Image 1** below.

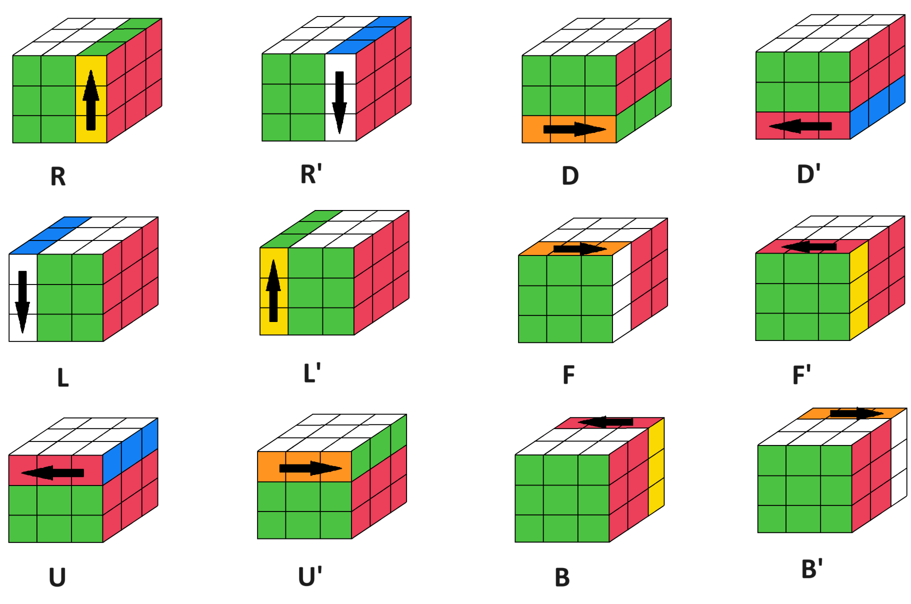

Image 1: Notation

One way to remember the above is that the letters stand for the position of the face you are turning (R for Right, L for Left, U for Up, D for Down, F for Front and B for Back) and the normal way of turning is clockwise (while the inverse is counter-clockwise). Finally, if a layer is turned twice, a "2" is added at the end. For example, R2 means turning the right layer 2 times.

2 First Layer

2.1 Edges:

The first step to solving the first layer is correctly placing all the edges of this layer. This is often also referred to as "The Cross". In this tutorial we select the white layer as starting point. First, hold the cube such that the white center piece is on the top. The edges are the pieces that have 2 colors. Therefore, we also have to solve them not only with regards to the top center piece, but also with regards to the center pieces on the adjacent sides. **Image 2** shows a correct and a wrong case with all the other pieces we do not care about for now grayed out.

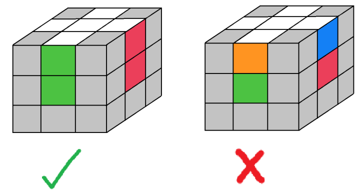

Image 2: The Cross

To solve the first step, we try to find an edge piece that contains white on the D-layer. If there is a white edge-piece on the D-layer, we can then freely turn it with D, D' or D2, until it is located under its correct position (you should turn the whole cube along, to follow its movement). From then on, there are two cases, that can be solved as shown in **Image 3** below.

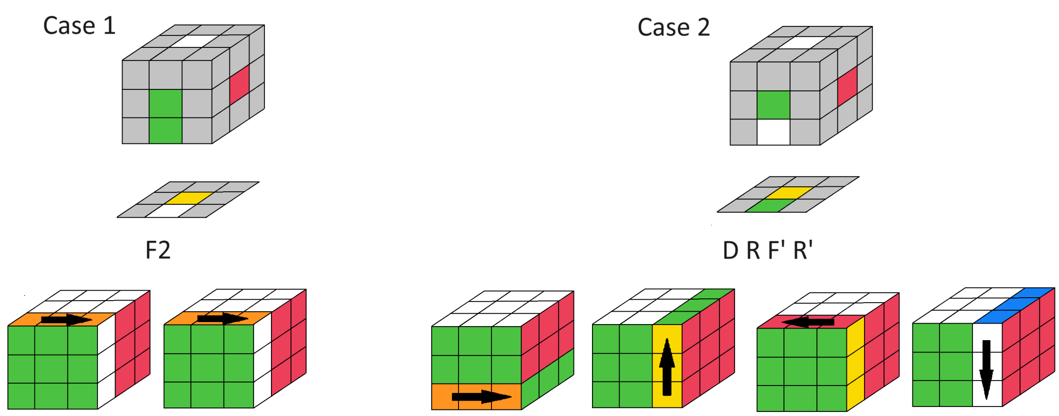

Image 3: The Cross: Cases 1 and 2

If there is no white edge-piece on the D-layer, it has to hide somewhere else. Wherever they are, they can be brought down to the D-layer quite easily, as shown in **Image 4**. Once you have done that, you can solve them as above. So, again move your piece below its correct position with D, D' or D2 and follow it. Then solve this white edge-piece either as Case 1 or Case 2 shown in **Image 3** above. If you practice for a while, you might notice that there are many special cases, for which more efficient solutions exist. Be bold and try to figure some out for yourself!

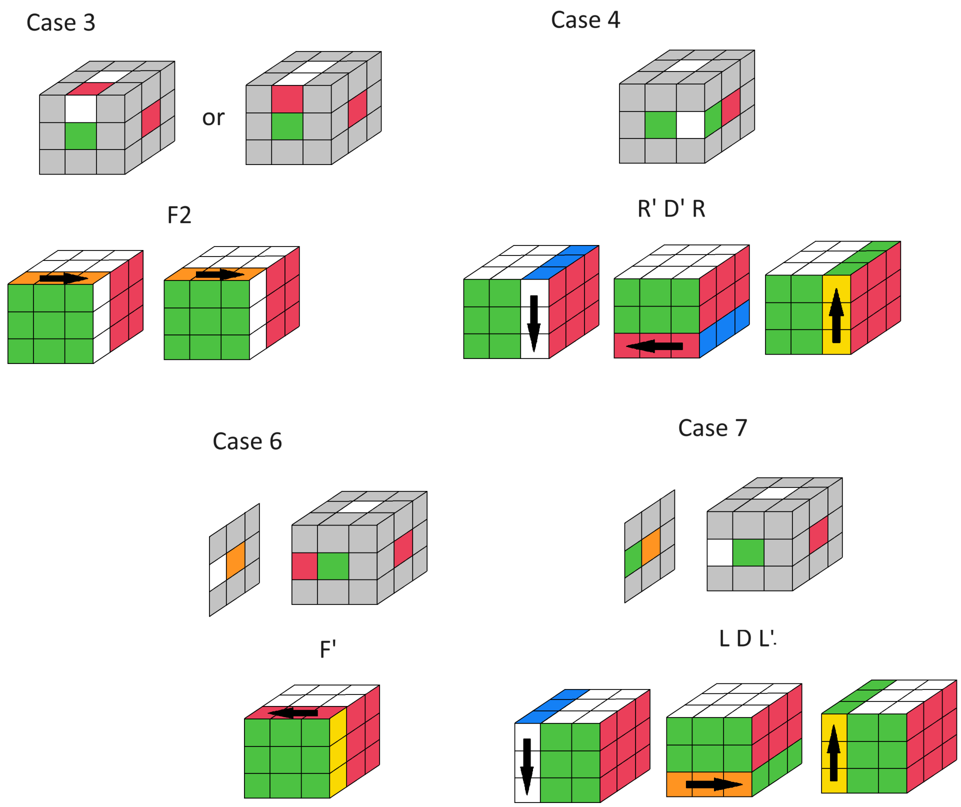

Image 4: The Cross: Cases 3 to 7

2.2 Corners:

In the next step, we are solving the corners of the first layer. Note that now we have to take care that all three colors match with the colors of the adjacent center pieces as shown at the illustration given in **Image 5** to the right.

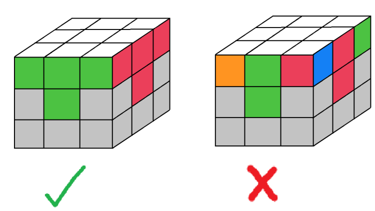

Image 5: First Layer

Similar to before, we firstly check, if we can find any of the white corner pieces in the bottom layer. If that is the case, then you can place them with D, D' or D2 movements under its correct location and follow it along. Once we complete this, we hold the cube such that the piece we want to solve is in the bottom right corner, and the position it belongs to is on the top right. Sometimes, a corner piece might be stuck in the correct location, but wrong orientation (cases 4 and 5 shown in **Image 4**). For those, the same logic applies, but holding now the corner in the top right instead of bottom right. Then, we perform the algorithm shown in **Image 6** repeatedly, until the piece is solved.

In very unlucky scenarios, you might find that all piece you want to solve are stuck in another piece's position in the first layer. In this case, you can perform the algorithm above once, holding the piece in the top right like in cases 4 and 5. After that, you will find this piece in the D-layer, where you can then proceed as before. It is of course the easiest to use only this one algorithm to solve this step, but again, you may find many more efficient ways to solving individual cases.

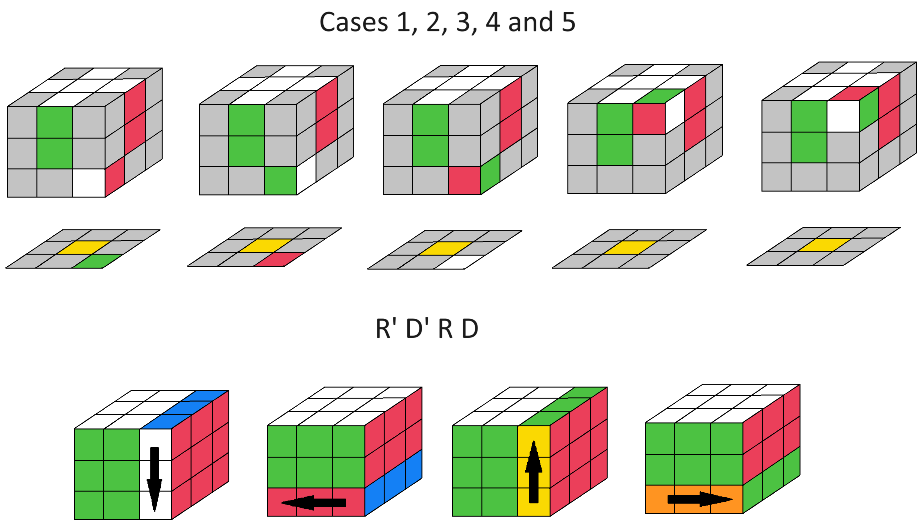

Image 6: Corners of the First Layer

3 Second Layer

Next, we continue with solving the second layer. Because we have been careful with solving the cross-edges to the correct center-piece colors at its adjacent sides, we only have to solve four pieces to complete the second layer!

First, we flip the cube such that the finished layer is at the bottom (here white is on the bottom side and yellow at the top). Then we have to identify the missing pieces of the second layer. These are also edge-pieces, like the cross-edges, but they contain all kinds of colors - except for the top and bottom layer! We want to find such a piece on the top layer (U-layer). If you can find one of these pieces, turn it with either U, U' or U2 (and follow it again, by rotating the cube along with it) such that its color on the front-side is the same as one of the center pieces. In **Image 7**, to the right, you can see an illustration of this. This works, because we can indeed freely turn the U-layer, since our solved side is now on the D-layer and neither of the U-moves (U, U' or U2) changes the D-layer.

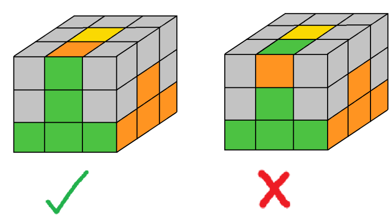

Image 7: Correctly placing the 2nd layer pieces

After this is done, we have to perform the next algorithm to solve this piece to its correct location. There are 2 cases: Either the second layer pieces have to go to the right or to the left. Depending on this, you perform either of the 2 algorithms shown in **Image 8**.

As with the first layer corners, there might be the case that all pieces you want to solve are stuck in the wrong position in the second layer. You can then perform one of the algorithms above to solve a random piece from the upper layer to the current location of one of the second layer pieces. Doing this returns the second layer piece to the top, where you can then again place it with U, U' or U2 to the correct center-piece and perform again Case 1 or 2 from above.

With this, you should be able to solve two full layers of cube, leaving only one remaining!

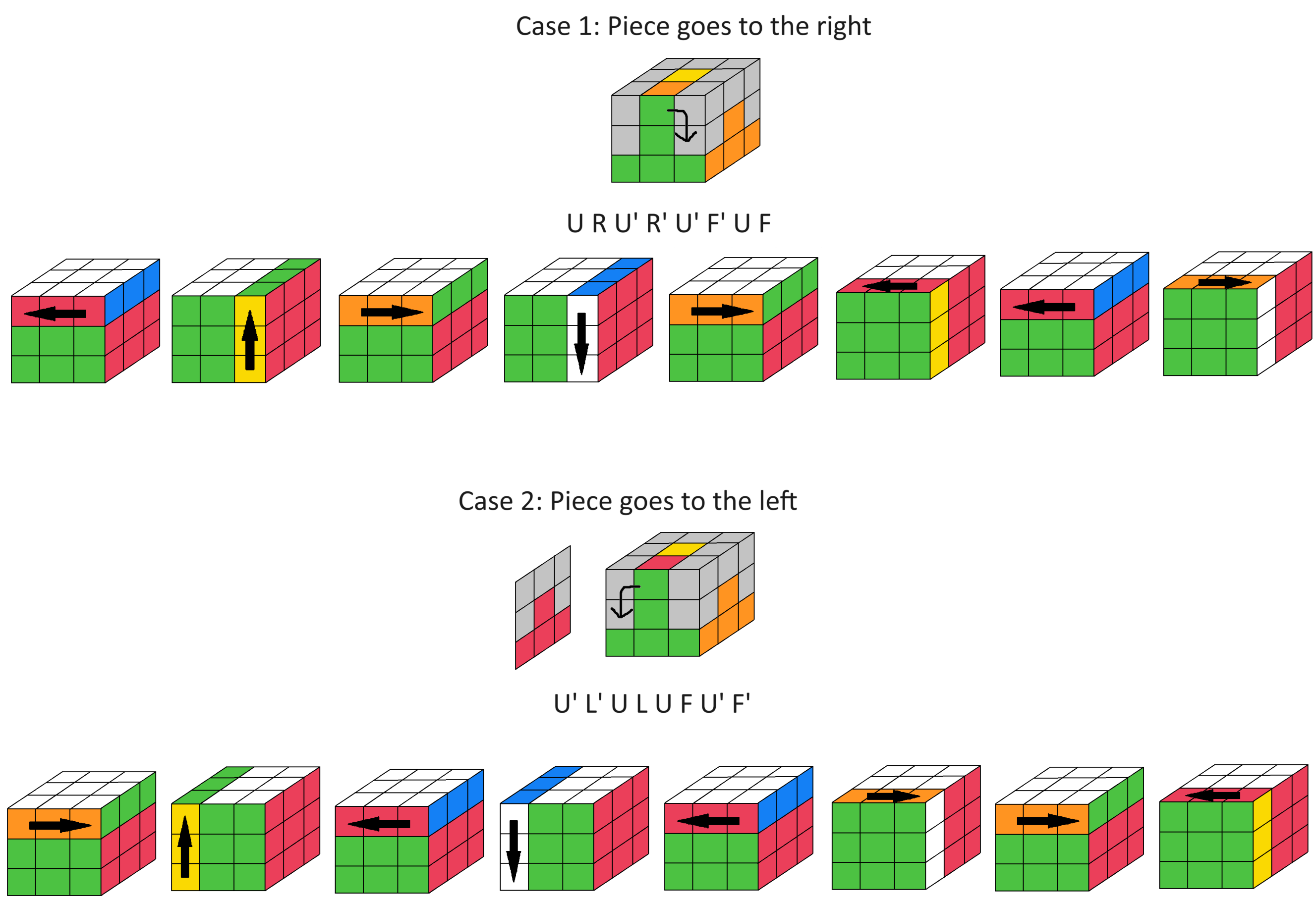

Image 8: Second Layer Algorithm

4 Last Layer

Solving the last layer of the Rubiks Cube is typically split into multiple steps. A rule of thumb is, the less steps you need for the last layer, the more algorithms one would have to learn. Here, we try to reduce the amount of algorithms we have to learn drastically, but we will need 4 substeps to complete the last layer (and with this the whole cube). The steps we will do are the following: 1) Solve the last layer edge-pieces (last layer cross), 2) Permute the last layer cross-pieces, 3) Permute the last layer corner-pieces and 4) Orient (and with this solve) the last layer corners.

4.1 Last Layer Cross - Part 1

To solve the cross of the last layer, we again hold the cube as before (solved first layer on the bottom). By only looking at the orientation of the last layer cross edge-pieces (so edge pieces that contain the color of the top center-piece), there are 4 possible cases: 1) the cross is already "solved", 2) there are two last-layer cross pieces on the top, and they are adjacent, 3) there are two last-layer cross pieces on the top, and they are located opposite to each other and 4) no cross pieces oriented correctly. To solve all of these cases, we only need one algorithm, but we might need to use it multiple times. In fact, case 4 will produce case 3, case 3 will produce case 2, and performing the algorithm for case 2 will solve the cross. In between each algorithm, we need to make sure to hold the cube correctly, so we perform the algorithm from the correct angle. To do this, you can again just turn the whole cube. The cases are illustrated in **Image 9** below, together with the correct orientation (how to hold the cube) and the corresponding algorithm.

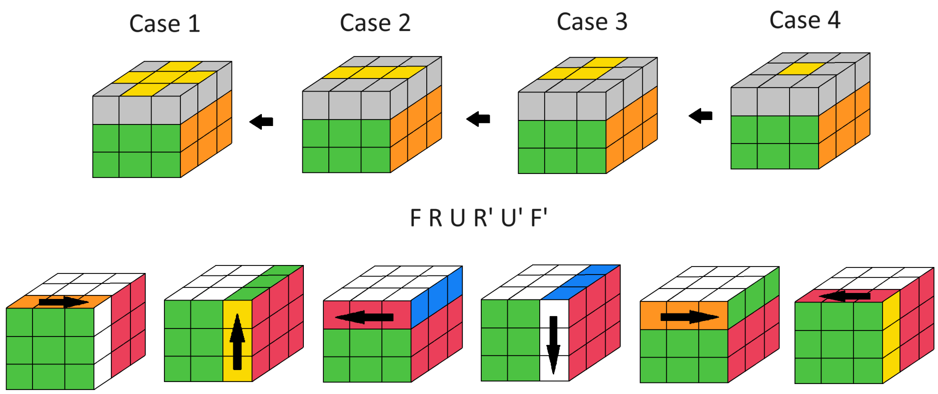

Image 9: Last Layer Cross Orientation

4.2 Last Layer Cross - Part 2

Now, we may have solved the cross at the top, but as with the cross at the first layer, we'd like to get the secondary colors of the cross-edges to match the center-piece colors on the sides too.

As in the previous step, we follow a scheme, where we only need to use one algorithm, but we may need to use it multiple times. We only can have 3 cases though: 1) The cross-edges are actually all at the correct position, 2) we need to exchange adjacent cross-edges or 3) we need to exchange the cross-edges that are opposite to each other. One important thing to note is that you are always allowed to use U, U' and U2 moves to align the top layer. If you do not see at least 2 cross-edges that match the center-pieces on the sides with their secondary color, then you need to apply U, U' or U2 to achieve this! Once this is done, we can apply the algorithm shown in **Image 10** below, with the cube held like in the image, which is especially important for case 2, where the wrong edges are placed in the front and in the left layer.
Case 3 actually works for both a wrong piece in front, as well as a correct one.

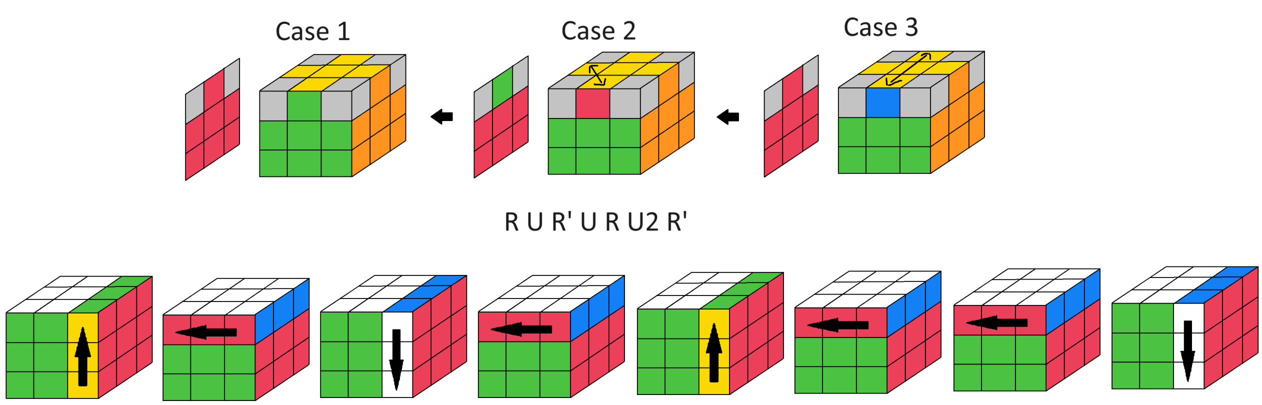

Image 10: Last Layer Cross Permutation

4.3 Last Layer Corners - Part 1

With the cross in the top layer now done, there are only 4 more pieces that need to be solved! We will again do this in 2 steps, so that we need to learn only 1 more algorithm (and re-use one from before).

In the first step, we only want to bring the corners, to their correct position. We notice that a corner is in the correct spot if it has the same 3 colors, as the 3 neighbouring center-pieces. For now, we do not care about if the piece is rotated correctly or not. An illustration can be seen in **Image 11**, considering the corner that is circled in purple.

Next, we count the number of these correctly placed corner pieces. Note that this time, we cannot rotate the top layer with U, U' and U2 moves, because this would mess up the cross we just made! There are 3 cases: 1) Either we have again all corners correctly placed, 2) one corner is correctly placed or 3) no corner is at its correct position.

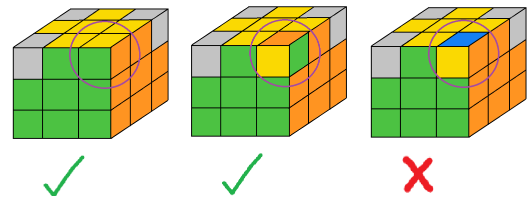

Image 11: How a "correctly placed" last layer corner looks like.

If we have case 3, that is no correct corner, then we may hold the cube as you like, except that the solved first layer needs to stay on the bottom. Otherwise, if we find one correctly placed corner, we hold the cube such as in **Image 11**, meaning that the correctly placed corner is in the top right position. This will preserve the corner, while we change the location of the other 3 with the algorithm shown in **Image 12**.

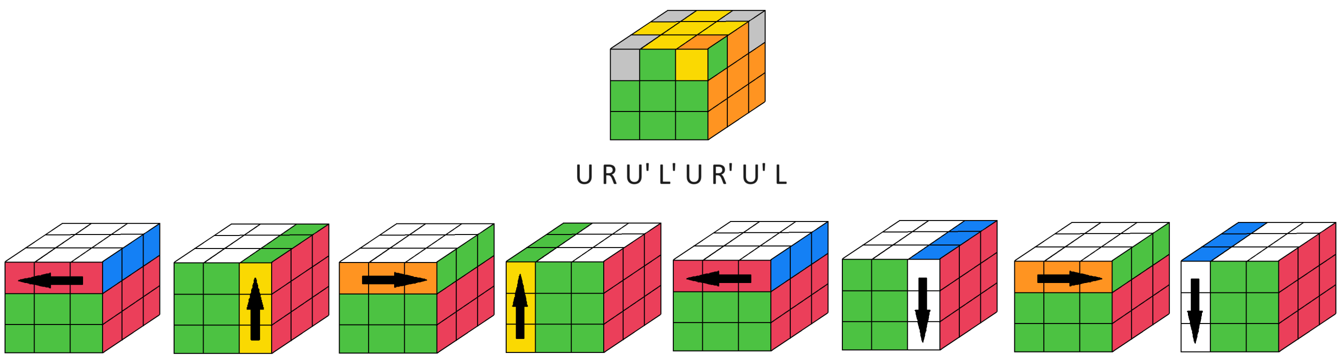

Image 12: Last Layer Corner Permutation

As in the previous steps, we might not end up with 4 correct corners after doing the algorithm once. If at first there was no good corner and then the algorithm is performed, there should be one correct corner afterwards. Then, the cube has to be rotated as a whole to have this correct corner in the top right location, and then we may need to do the algorithm once or twice more. If all the last layer corners are in their correct spot, the last thing to do is to rotate them and we are done!

4.4 Last Layer Corners - Part 2

To finally solve the cube, we need to rotate the last layer corners - without destroying anything we did before. To do this, we actually need to use the algorithm from solving the corners of the first layer. First, we pick one of the corners that are not fully solved yet and place it again into the top right position by rotating the whole cube (you can have either 2, 3 or all 4 corners that need to be rotated). Once this is done, we repeat our corner-algorithm from the first layer, until this one piece is solved. You will notice that once this piece is rotated correctly, the bottom part of the cube seems messed up - if you do everything correctly, there is no need to worry about this! We just proceed by solving the other corners now. **BUT:** we do not rotate the whole cube to bring the next corner to the top right position, instead we rotate only the top layer (by doing a U, U' or U2 move), such that the next corner piece is at the top right. This is very important, because this will fix the mess in the end. Repeat this for every wrongly rotated corner, and in the end, there should only be a U, U' or U2 move left to solve the whole cube. An illustration of this last step is given below, in **Image 13** where we go through an actual 2 corner case, and how the cube looks at each sub-step.

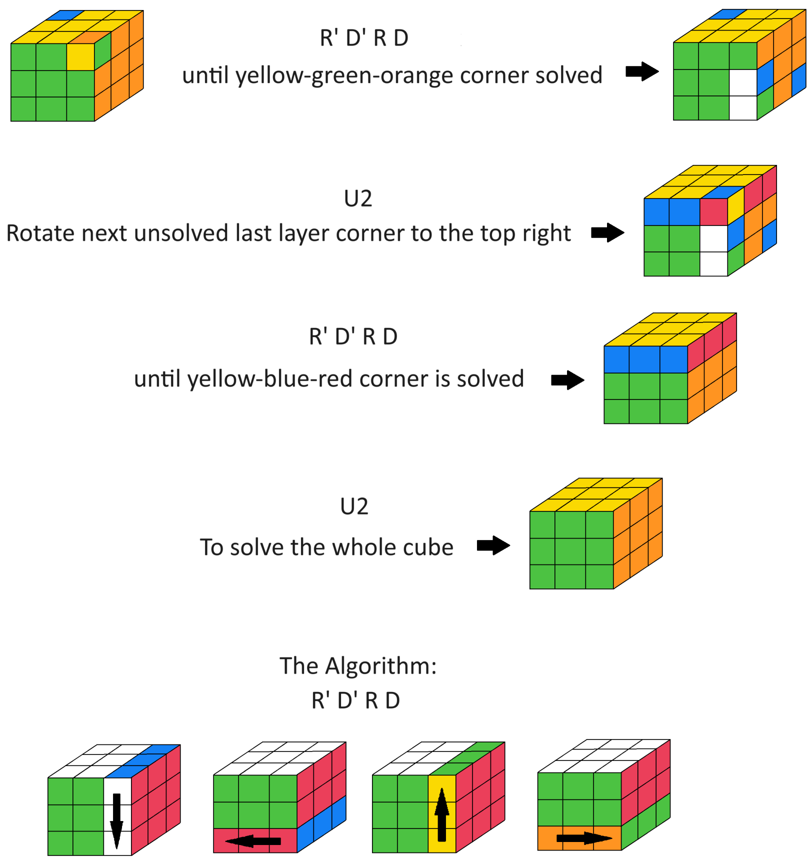

Image 13: Solving the last layer corners.

5 Final Words

In this (hopefully useful) tutorial, we learned a rather simple approach to solving the Rubik's Cube. Maybe some have already heard or seen that there is a group of dedicated people practicing something called "Speedcubing", which means solving the Rubik's Cube and related puzzles as quickly as possible. I may note that the method presented here is a good starting point, and with a bit of practice, one can easily solve the cube in under a minute with this method (with a lot of dedication also below half a minute!), but there are more suited methods for solving it fast. These methods however are more complex and typically involve learning more algorithms (some of them also reaching above 15 turns that one has to memorize). Probably the most popular ones are called Roux and CFOP. For both, there are tons of resources online, so if you are interested, you will for sure find good tutorials and videos on various platforms.

If you are interested in solving more puzzles, there are plenty more you can easily find. There is a smaller version to the 3x3x3 Rubik's Cube, which is the 2x2x2 Cube - if you followed this tutorial, you should even be able to piece the solution together yourself! There are also bigger cubes (my personal favorites), going from 4x4x4 to massive sizes like 21x21x21 (even though the very big ones are super expensive, and competitions are only held up to a size of 7x7x7, which is already quite big!). It also does not stop at cubic puzzles, there are other fun non-cubic puzzles like for example Pyraminx, Megaminx, Skewb, and many more. As impressive as the Megaminx looks like, if you cleverly piece together everything you have learned in this tutorial, you might be able to solve it already!

Finally, I hope this tutorial was useful and maybe I inspired one of you to pick up the cube and find a fun new hobby.

The Sun in different colors

1 Just some facts about the Sun

The Sun, at the heart of our solar system, is a big ball of hot gas. At the core of the Sun, the temperature is a dazzling 15 million (15 000 000) degrees Celsius. That is over ten thousands times hotter than the lava erupting from the volcano. As we move from the core outward towards the Sun's surface the temperature drops to about 5600 degrees. However, an interesting thing happens above the Sun's surface. The temperature suddenly dashes up again and reaches 1 million (1 000 000) degrees Celsius in the region called the solar corona ("the crown of the Sun"). This phenomenon, called coronal heating, is a great mystery. Because the Sun is so hot, the gas in it has converted to the fourth state of matter called plasma. Fun fact; you can find plasma at Earth too, in neon signs or in the sky during a lightning or aurora. In plasma atoms break apart forming a "soup" of electrons and nuclei (**Image 14**).

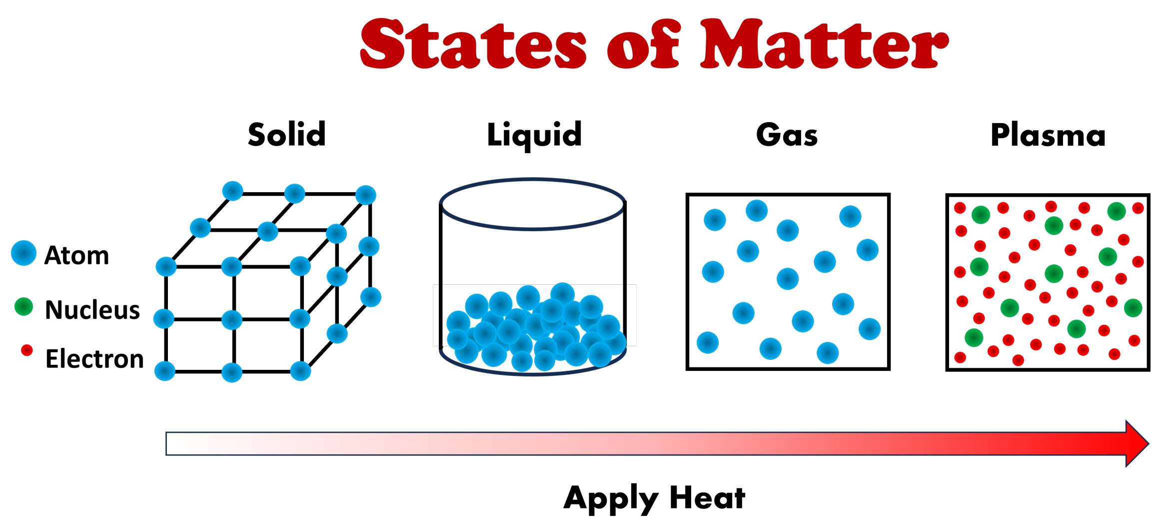

Image 14: The different states we can find matter in nature and how applying heat takes us from solid state to liquid, to gas, and at last to plasma state. *Image credit: Eleanna Asvestari*

The Sun produces its own magnetic field in its interior in a process involving complex movements of the plasma. You probably have heard that the Sun is like a giant magnet! It has a north pole and a south pole (these poles switch their place every 11-years!). The magnetic field stretches into the solar corona forming big magnetic loops. Some of these loops are carried away from the Sun by a constant flow of plasma called the solar wind. The plasma and magnetic field from the Sun hit our planet. They can cause big disturbances in the Earth's magnetic field and the beautiful aurora we so often enjoy on the Finnish night sky.

The Sun can therefore affect our technology in space and on the ground. As you can imagine, it is important to understand them. And, to do that we need to understand their source, the Sun. In Solar Physics we do that with physics based theory, big computational models, and of course observations!

2 The Sun of the many temperatures

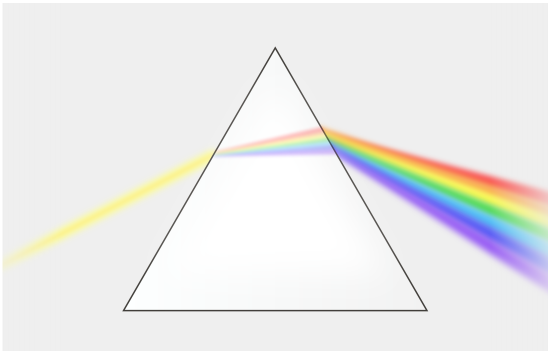

Image 15: The visible light travelling through a prism *Image credit: Suidroot on Wikimedia Commons.*

As we learned so far, the plasma on the surface of the Sun and throughout its corona exists in a wide range of temperatures. The plasma in different temperatures radiates light having different wavelengths. In fact, the Sun radiates light from very short wavelengths such as X-rays to long radio wavelengths. We thus take photos of the Sun with cameras that have different filters to only allow light of a specific wavelength to be captured. This provides us with information of different layers and structures of the Sun's atmosphere, and solar eruptions.

Before we take a look at how the Sun looks at different wavelengths, let us remember the classical experiment with light travelling through a prism. When this happens on the other side of the prism we see an array of colours Each of these colors has a different wavelength. All these colors combined form what we call the white light. From space the Sun looks white as it radiates strongly all the wavelengths of the visible light

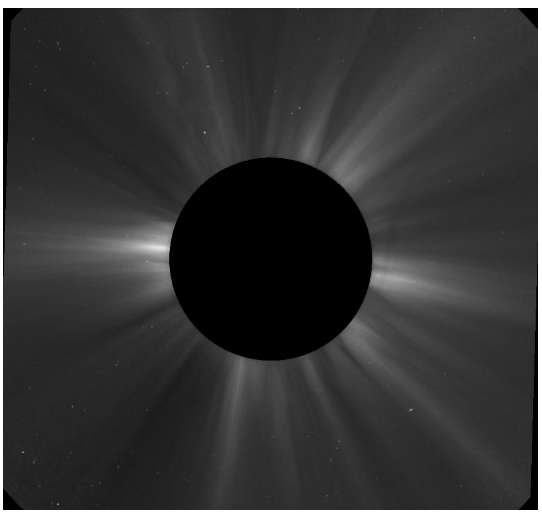

Image 16: The solar corona observed in white(visible)-light with the LASCO C2 telescope onboard the SOHO spacecraft and visualised using the JHelioviewer tool.

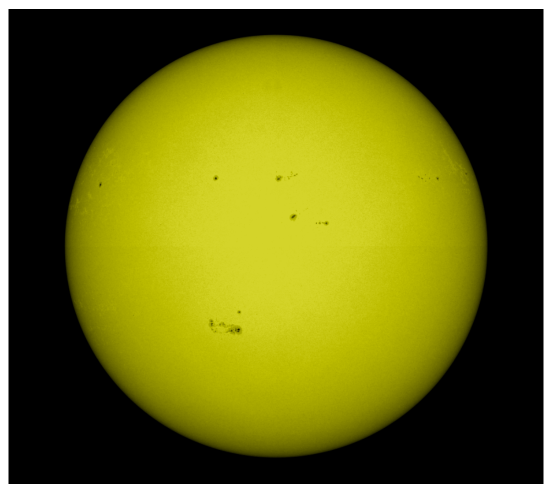

Image 17: The Sun observed at 4500 Å wavelength with the AIA space telescope onboard the Solar Dynamics Observatory and visualised using the JHelioviewer tool.

From Earth we however see the Sun shine as yellow. This is because the sunlight has passed through the atmosphere where certain wavelengths of light scatter away. We can also see the solar corona in white-light. If you ever witness a total solar eclipse, you will be able to see the corona! In solar physics we mimic the solar eclipse with an instrument called the coronagraph. This instrument has a disc in the middle of the telescope lens, that blocks the bright solar disk, allowing us to see the solar corona like in **Image 16**. All these fine lines are giving us an idea of how the magnetic field in the solar corona looks like.

If we want to see the solar surface, also known as the photosphere, we need to observe the Sun with a camera using a filter that can see plasma at temperatures of approximately 5600 degrees Celsius. The plasma at this temperature emits in white-light at a wavelength around 4500 Å (1 Ångstrom is only 1^{-10} meters.**Image 17** shows a photo of the Sun taken exactly with that filter. Do you see those dark spots on it? These are known as sunspots and they can tell us a lot about how active the Sun is!

What does the Sun look like if we use cameras with filters that are sensitive to wavelengths beyond the visible light? Well, let's have a look!

Now, if we want to observe the plasma structures that are a bit hotter, for example at around 50.000 degrees Celsius, we will need a filter that observes light with a wavelength of 304 Å. These plasma structures are above the solar surface, in a region called the upper photosphere. Let's have a look at it in **Image 18**. This wavelength belongs to the portion of the spectrum called Extreme Ultra Violet (EUV). As you can see at this wavelength the Sun appears like a sea of lava. The very bright, almost white structures are called Active Regions, and as you guessed from their name they are very active. They often erupt giving birth to solar storms. If you look at the image carefully, you will see some darker wavy structures known as filaments. They can live for many-many days, but often they also erupt generating solar storms.

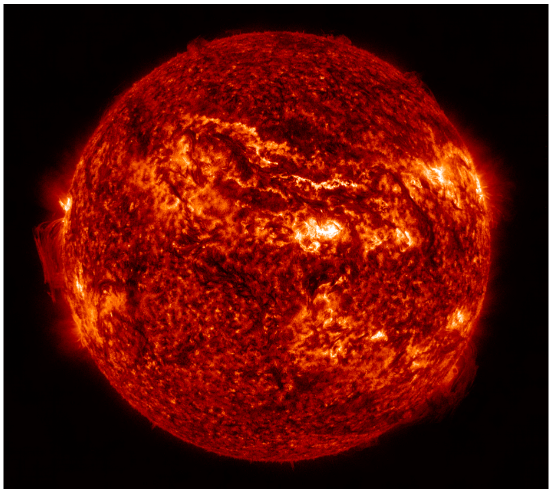

Image 18: The Sun observed at 304 Å wavelength with the AIA space telescope onboard the Solar Dynamics Observatory and visualised using the JHelioviewer tool.

The Sun is observed with several other EUV filters that reveal hotter and hotter plasma. At almost million (1 000 000) degrees Celsius we observe light of 193 Å. This light was emitted by plasma in the low corona, about a few thousands kilometers above the photosphere. **Image 19** is a photo of the Sun at that wavelength. Active regions have now become even brighter and bigger. Take a look at how tall structures they are! The Sun looks a bit hairy at this wavelength! All these fine lines surrounding the Sun are related to the Sun's magnetic field.

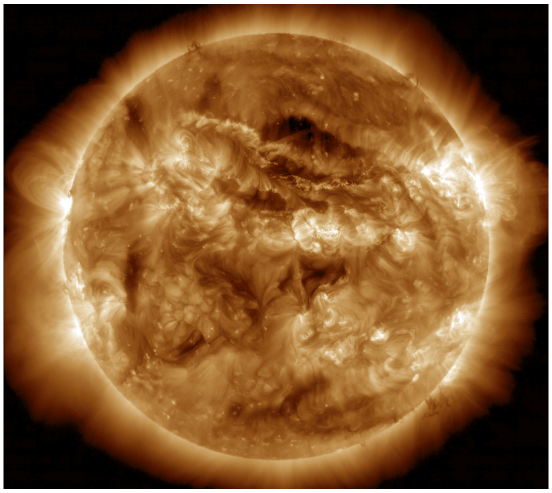

Image 19: The Sun observed at 193 Å wavelength with the AIA space telescope onboard the Solar Dynamics Observatory and visualised using the JHelioviewer tool.

Let's take a look at how the Sun looks at 335 Å where the plasma is almost 2.5 million (2 500 000) degrees Celsius. In **Image 20** there are less details visible on the solar disk. This is because only a few structures in the low solar corona are that hot. Active regions are these bright structures. And at 94 Å where the light is emitted by plasma as hot as 6 million (6 000 000) degrees Celsius only the hotter parts of Active Regions are still visible as you can see from Image **Image 21**. If one of them erupts then this can observe at this wavelength.

These are only some examples of the wavelength we observe the Sun at. And as you can see each reveals something more, or something different comparing to others!

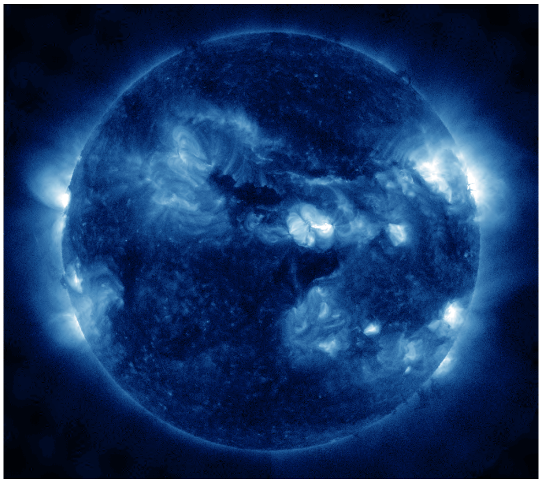

Image 20: The Sun observed at 335 Å wavelength with the AIA space telescope onboard the Solar Dynamics Observatory and visualised using the JHelioviewer tool.

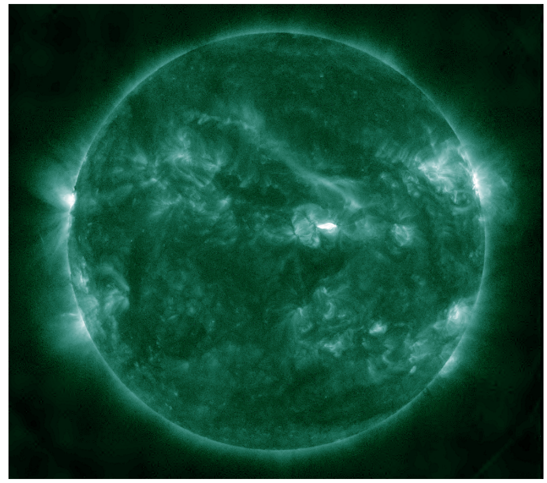

Image 21: The Sun observed at 94 Å wavelength with the AIA space telescope onboard the Solar Dynamics Observatory and visualised using the JHelioviewer tool.

3 Seeing the magnetic field

At the start of this chapter we discussed that the Sun is a giant magnet. All the structures we saw in the previous images of the Sun at different wavelengths are associated with the Sun's magnetic field. It is therefore important to be able to capture it. That is made possible with an instrument called magnetograph, and which measures the strength of the Sun's magnetic field. With this information we can create images of the solar disk, called magnetograms, and which are showing us spatial variations of the strength of the Sun's magnetic field on the disk. A magnetogram is shown in **Image 22**. In white colour you can see areas where the magnetic field is positive, thus pointing away from the Sun, and with black you see areas where the magnetic field is negative, thus pointing towards the Sun. Notice how there are patches of paired black and white structures. These are associated to the active regions we observed in EUV in the previous images.

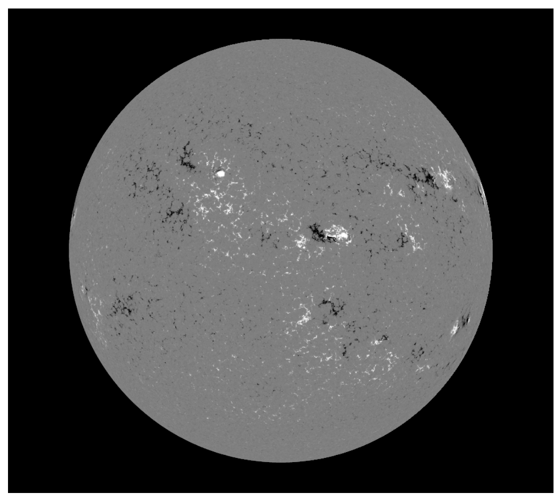

Image 22: A magnetogram showing the spatial variations of the Sun's magnetic field strength measured with by the HMI magnetograph onboard the Solar Dynamics Observatory and visualised using the JHelioviewer tool.

All this information might be too much to digest in one read, but if you ever have any questions about these or the Sun-Earth space and relations feel free to contact the researchers of the Space Weather Research Group at the University of Helsinki.