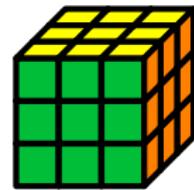


Typesetting the cube

ukTUG Nov 2013

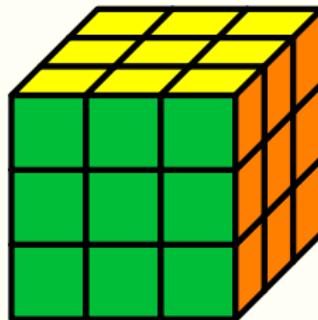


RWD Nickalls
dick@nickalls.org
Cheltenham, UK

Overview

- 1 *Background & motivation*
- 2 *Some code*
- 3 *Examples*

Supported by ukTUG coffee



CERN and Higgs *et al.*



Peter Higgs, François Englert y Sergio Bertolucci, director de investigación del CERN, participan en un encuentro científico en la Facultad de Ciencias de la Universidad de Oviedo. Foto: © Iván Martínez/FPA

CERN and Rubik's cube (2011)

—student project wins prize



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Celebrating a very scientific Endeavour

LHC Report: Summertime and the living is ZZ (and WW etc.)

1912 – 2012: a century of studying cosmic rays

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Bringing physics training to Africa

Over one million followers reached in CERN TweetUp

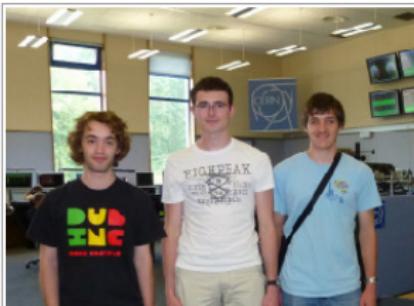
CERN's attentive ear: the first 18 months

Rubik's cube, an original subject for a remarkable project

French Prime Minister tours CERN

Rubik's cube, an original subject for a remarkable project

Thanks to a Rubik's cube, young French students Florentin Delaine, Joseph Gennetay and Jason Loyau won a week-long visit to CERN at the European Union's 2011 contest for young scientists ([EUCYS](#)). They spent 17 to 24 July exploring the Laboratory.



"It all started with a friend who was playing with a Rubik's cube. At our lycée, we had to choose a subject for a research project. We thought it would be fun to build a robot to solve the puzzle," recounts Jason. Two years later, their entry in the internationally recognised [EUCYS 2011](#) competition, for young scientists between 14 and 20 years, was a prizewinner.

Rubik cube in the news

Tom Rokicki (2013) — only 20 moves required

SIAM J. DISCRETE MATH.
Vol. 27, No. 2, pp. 1082–1105

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THE DIAMETER OF THE RUBIK'S CUBE GROUP IS TWENTY*

TOMAS ROKICKI[†], HERBERT KOCIEMBA[‡], MORLEY DAVIDSON[§], AND JOHN
DETHRIDGE[¶]

Abstract. We give an expository account of our computational proof that every position of Rubik's Cube can be solved in 20 moves or less, where a move is defined as any twist of any face. The roughly 4.3×10^{19} positions are partitioned into about two billion cosets of a specially chosen subgroup, and the count of cosets required to be treated is reduced by considering symmetry. The reduced space is searched with a program capable of solving one billion positions per second, using about one billion seconds of CPU time donated by Google. As a byproduct of determining that the diameter is 20, we also find the exact count of cube positions at distance 15.

[†] Computer scientist, Palo Alto, California, USA.
Wrote the \TeX driver dvips (dvi-to-PostScript translator) in 1985.

Rubik cube as a teaching tool

- Mathematics:
 - a good example for highlighting aspects of group theory.
- Physics:
 - the 6 cube faces (\equiv colours & flavours)¹ and 8 corner cubies (\equiv quarks) with their rotational assignments (mod 3), and the general symmetry all make the cube a useful example offering some insight into the laws of particle physics, especially for quarks. This was first noticed by the mathematician Solomon Golomb.²
 - a 2x2x2 cube is therefore sufficient for the physicists!

¹The first two flavours were ‘up’ and ‘down’!

²Golomb SW (1982). Rubik’s cube and quarks. *American Scientist*; 70, pp. 257–259. [JSTOR]

Rubik's cube and Quarks

American Scientist (1982); 70, pp. 257–259

Solomon W. Golomb

Rubik's Cube and Quarks

Twists on the eight corner cells of Rubik's Cube provide a model for many aspects of quark behavior

The geometric puzzle known as Rubik's Cube™ has achieved worldwide popularity and has recently been featured in articles in many publications, ranging from *Scientific American* to *Reader's Digest* to *Time* and the *Wall Street Journal*. Somewhat surprisingly, the eight corner cells, or "cubies,"

whole numbers. The restrictions governing the allowed combinations are referred to as the principles of quark confinement. (Ref. 2 gives an account of the role of quarks in current physical theory.)

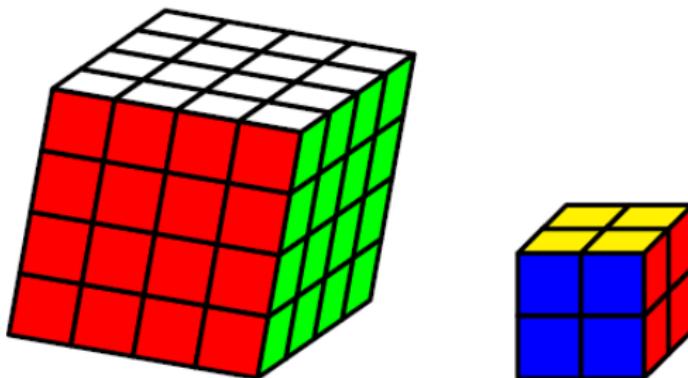
The relationship between Rubik's Cube and quarks comes about as

ered physical phenomena such as those reported in October 1980 in *Science* (3) may correspond to metastable combinations such as three quarks and three antiquarks, a reasonable configuration to obtain on Rubik's Cube.

Physical Review Letters

Motivation

- I wanted to document some Rubik cube sequences I had developed, but ...
 - difficult to draw & orientate the cube
 - no \LaTeX .sty available
- Google search → some TikZ code by Peter Bartal (2011), aka “Count Zero” — in: *Show off your skillz*
<http://tex.stackexchange.com/questions/34482>



Plan:

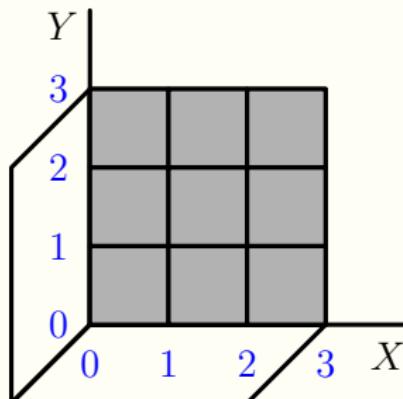
rubikcube package

- 'rubikcube' T_EX package with Apostolos Syropoulos
- Nomenclature & command-names
- Cubes of different size 2x2x2, 4x4x4 → ? package extensions / different packages
 - would need a coherent nomenclature / system
- ? use LuaT_EX for drawing nice rotation images
- Involve other interested folk

Commands

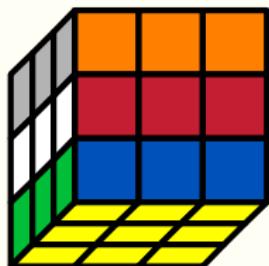
DrawRubikcubeFrontFace

```
\newcommand{\DrawRubikcubeFrontFace}{%
%---top row
\draw[line join=round,line cap=round,
      ultra thick,fill=\Ftl] (0,2)  --
(0,3) -- (1,3) -- (1,2) -- cycle;
...
%---middle row
...
%---bottom row}
```



Commands

colours



```
\colorlet{X}{black!30}%
\colorlet{O}{orange}%
\colorlet{W}{white}%
\definecolor{R}{HTML}{C41E33}%
\definecolor{G}{HTML}{00BE38}%
\definecolor{B}{HTML}{0051BA}%
\definecolor{Y}{HTML}{FFFF00}%
%% initialise faces to default grey
\RubikFaceFrontAll{X}
\RubikFaceUpAll{X}
\RubikFaceDownAll{X}
\RubikFaceLeftAll{X}
\RubikFaceRightAll{X}
```

Commands

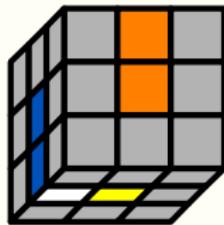
colour & RubikFace commands 1

```
\RubikFaceLeft{X}{X}{X}{X}{B}{X}{X}{B}{X}%
\newcommand{\RubikFaceLeft}[9]{%
  \def\Ltl{#1} \def\Ltm{#2} \def\Ltr{#3}%
  \def\Lml{#4} \def\Lmm{#5} \def\Lmr{#6}%
  \def\Lbl{#7} \def\Lbm{#8} \def\Lbr{#9}%
}%
```

Commands

DrawRubikcube commands

```
\newcommand{\DrawRubikcubeFrontFace}  
\newcommand{\DrawRubikcubeRU}  
\newcommand{\DrawRubikcubeLU}  
\newcommand{\DrawRubikcubeRD}  
\newcommand{\DrawRubikcubeLD}
```

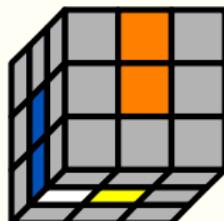


```
\DrawRubikcubeLD
```

Commands

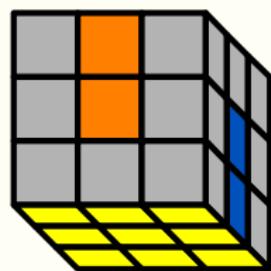
colour & Draw commands 2

```
\RubikFaceLeft {X}{X}{X}{X}{B}{X}{X}{B}{X}%
\RubikFaceFront{X}{0}{X} {X}{0}{X} {X}{X}{X}%
\RubikFaceDown {X}{X}{X}%
{W}{Y}{X}%
{X}{X}{X}%
\DrawRubikcubeLD
```



Commands

picture environment & command structure



```
\begin{minipage}{2cm}
\centering
\begin{tikzpicture} [scale=0.5]
    \RubikFaceFront{X}{O}{X}%
    {X}{O}{X}%
    {X}{X}{X}%

```

```
\RubikFaceRight{X}{X}{X}%
{X}{B}{X}%
{X}{B}{X}%
```

```
\RubikFaceDownAll{Y}
```

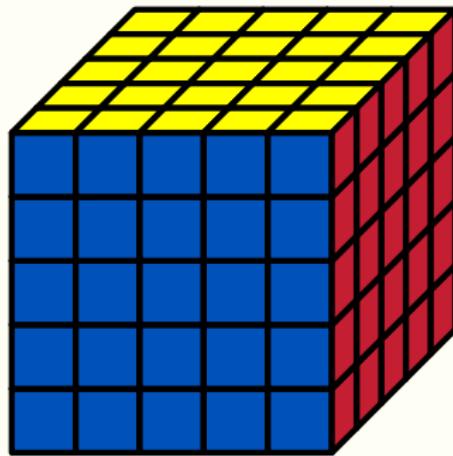
```
\DrawRubikcubeRD
\end{tikzpicture}
\end{minipage}
```

Commands

Ncube command



```
\DrawNcubeAll{1}{G}{W}{0}
```



```
\DrawNcubeAll{5}{R}{Y}{B}
```

Text commands

cubies

For convenience, there are also four (smaller) ‘text’ versions of the four DrawCubie commands  for use in ordinary text. The Cubie ‘text’ commands are not influenced by the Cubie dy dx commands (their values are set at: $dy = dx = 0.4$)



\textCubieRU{O}{Y}{G}



\textCubieLU{O}{Y}{G}



\textCubieRD{O}{Y}{G}



\textCubieLD{O}{Y}{G}



WORLD CUBE ASSOCIATION

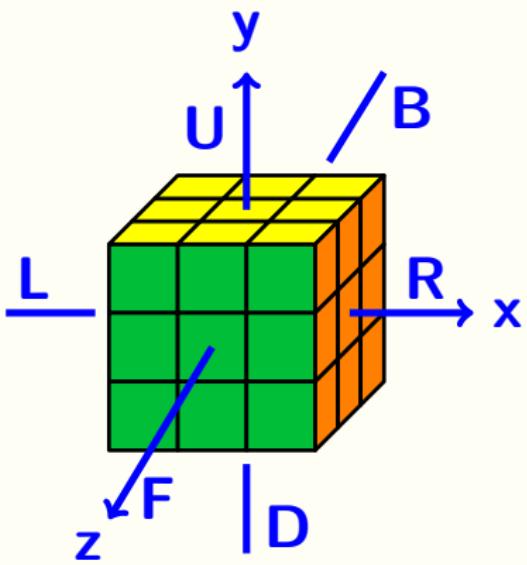
World Cube Association Competition Regulations (2013).

§ 12: Notation.

www.worldcubeassociation.org/

Notation

Singmaster * notation (1982)



* Frey AH and Singmaster D (1982). *Handbook of cubik math.* (Lutterworth Press, Cambridge, UK)

Square-box notation

both figure and in-line text forms

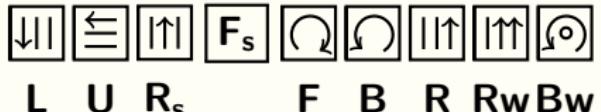
`\RubikU\RubikU\RubikR\RubikR` gives 

`\textRubikU` gives **U** 

`\rrU2 \rrR2` gives **U^2R^2** and forms a subgroup (order 6)

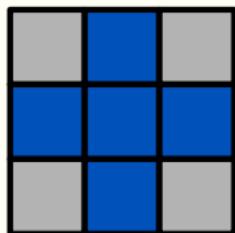
Let `\newcommand{\RI}{[2]{#1^{#2}}}`
then `\RI{\rrU}{2}` gives **U^2**

`\rrhU\rrhU\rrhR\rrhR` gives 

 and axis rotations **[x][y][z]**

LayerFace commands

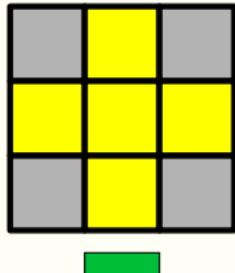
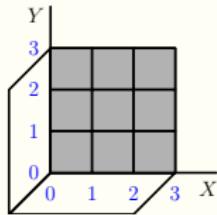
defining and drawing a single face



```
\begin{tikzpicture} [scale=0.7]
  \DrawRubikLayerFace{X}{B}{X}
  {B}{B}{B}
  {X}{B}{X}
\end{tikzpicture}
```

SideBars

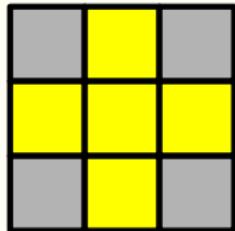
```
\def{\RubikSideBarWidth}[1]{\pgfmathsetmacro{\bw}{#1}}
\def{\RubikSideBarLength}[1]{\pgfmathsetmacro{\bl}{#1}}
\def{\RubikSideBarSep}[1]{\pgfmathsetmacro{\bs}{#1}}
```



```
\newcommand{\sidebarB}[2]{%
%% #1 = cubie possn no, #2 = colour
\pgfmathsetmacro{\blh}{\bl*(0.5)}
\pgfmathsetmacro{\dx}{#1 -1+0.5-\blh}%
\pgfmathsetmacro{\dy}{0 -\bs-\bw}%
\draw[fill=#2] (\dx,\dy) -- (\dx,\dy + \bw)
-- (\dx+\bl,\dy+\bw) -- (\dx+\bl,\dy)
-- cycle; }
```

SideBars

Width, Length, Separation



```
\DrawRubikLayerFace{X}{Y}{X}
{Y}{Y}{Y}
{X}{Y}{X}
```

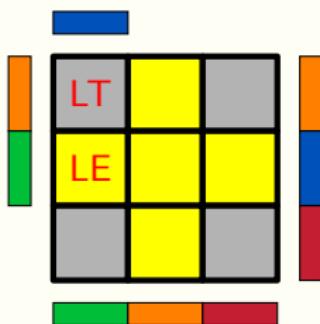
```
\RubikSideBarWidth{0.7}
\RubikSideBarLength{0.7}
\RubikSideBarSep{1}
\DrawRubikLayerSideMB{G}
```



```
\newcommand{\DrawRubikLayerSideMB}[1]{\sidebarB{2}{#1}}
\sidebarB{2}{G}
```

LayerSide commands

defining and drawing side colours



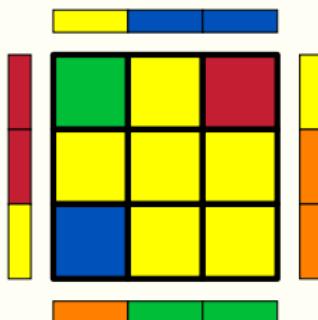
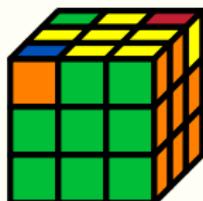
```
\begin{tikzpicture}[scale=0.7]
    \DrawRubikLayerFace{X}{Y}{X}
    {Y}{Y}{Y}
    {X}{Y}{X}

    \DrawRubikLayerFace
    \DrawRubikLayerSideLTy{B}
    \DrawRubikLayerSideLTx{O}
    \DrawRubikLayerSideLE{G}
    \DrawRubikLayerSideR{O}{B}{R}
    \DrawRubikLayerSideB{G}{O}{R}
    \node (LT) at (0.5, 2.5)
        [red]{\small\textrm{sf}{LT}};
    \node (LE) at (0.5, 1.5)
        [red]{\small\textrm{sf}{LE}};

\end{tikzpicture}
```

LayerSide commands

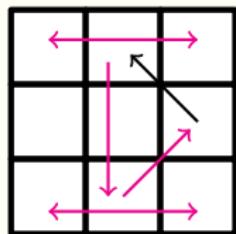
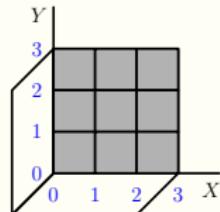
defining and drawing side colours



```
\begin{tikzpicture}[scale=0.7]
    \DrawRubikLayerFace{G}{Y}{R}
        {Y}{Y}{Y}
        {B}{Y}{Y}
```

```
\DrawRubikLayerSideT {Y}{B}{B}
\DrawRubikLayerSideLR{R} {Y}
{R} {O}
{Y} {O}
\DrawRubikLayerSideB {O}{G}{G}
\end{tikzpicture}
```

Arrows



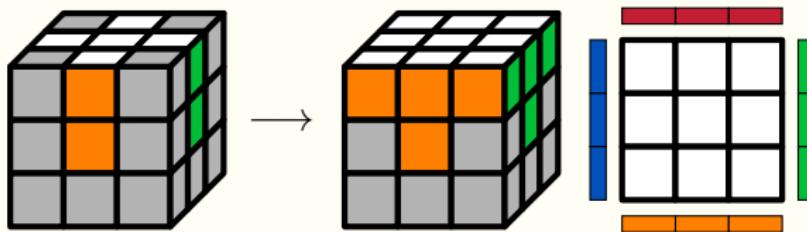
```
\begin{tikzpicture}[scale=0.7]
\DrawRubikLayerFaceAll{W}

\draw[->,thick,color=magenta] (1.5,0.5) -- (2.4, 1.4);
\draw[->,thick] (2.5,1.5) -- (1.6, 2.4);
\draw[->,thick,color=magenta] (1.3, 2.3) -- (1.3, 0.5);
\draw[<->,thick,color=magenta] (0.5,2.6) -- (2.5, 2.6);
\draw[<->,thick,color=magenta] (0.5,0.3) -- (2.5, 0.3);

\end{tikzpicture}
```

Solving the first layer

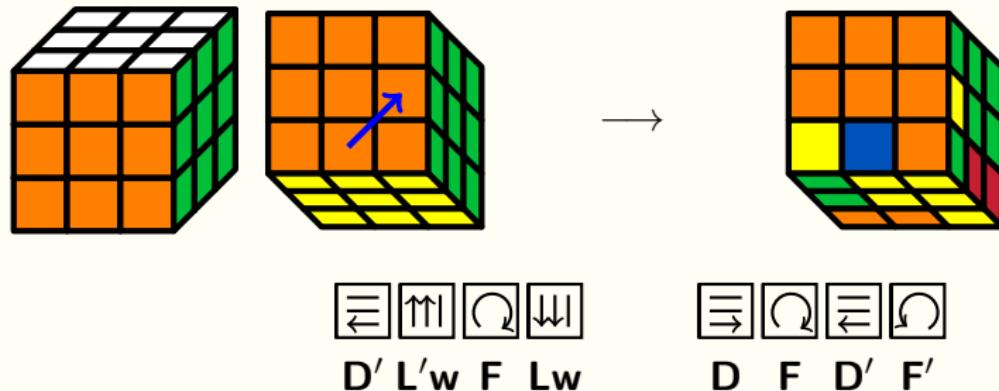
white cross → completion of first layer



- starting with white cross
- solve the four corners

Middle layer exercise

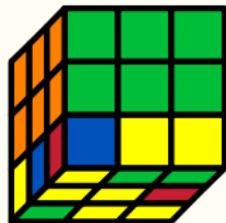
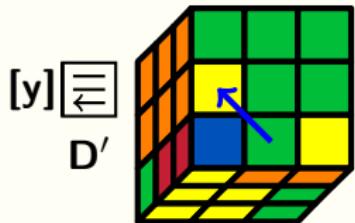
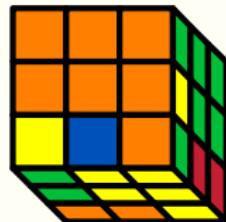
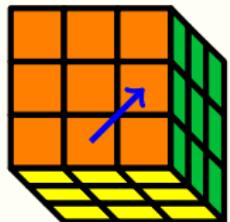
stage 1



- Move a cubie from bottom layer into middle layer
- This sets up an unsolved middle layer without having to first scramble the cube and then solve the top layer each time

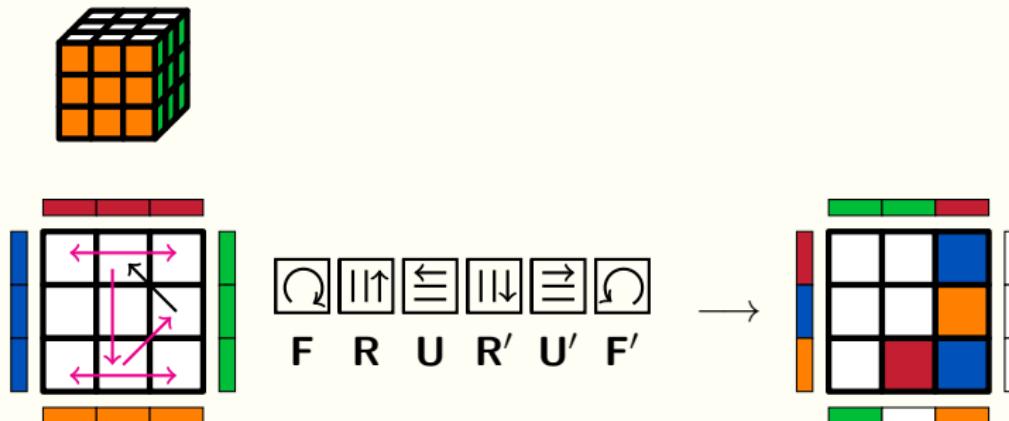
Middle layer exercise

two mirror-image sequences: R & L



Aim = cyclic rotation of three edge-cubies

Collateral = pairs of corner-cubies swap over



- Two of the three edge-cubies flip over; the third does not flip.
- BUT ... in this setting three edge-cubies can only change position cyclically, and only if four other cubies of a different 'flavour' (corner cubies) also swap position in pairs *and* 'spin'.
- Spin is conserved: $(1, 2)(3, 4, 5)(6, 7)$
3 edges: $\rightarrow \pi + \pi + 0 \equiv 0$
4 corners: $\rightarrow (0 + \pi/3) + (0 - \pi/3) = 0$

Several different solution systems

- There are several quite different approaches to solving the cube, and each requires a set of special commands and images to describe them fully.
- I have only covered commands and images associated with the so-called ‘layer’ approach for the 3x3x3 cube.
- There are cubes of many sizes, from $2 \times 2 \times 2 \rightarrow 11 \times 11 \times 11$, all with different notations too.
- — plenty of scope for lots of different or ‘extension’ packages, and so some careful thought needs to be given regarding names and commands to avoid confusion.
- I suggest we reserve the name “rubik” or “rubik3” for the 3x3x3 package. A package dealing with the 2x2x2 cube might be named, say, the “rubik2” package, perhaps.

We need a command to typeset a layer rotation: any layer, any angle, either direction, plus colours etc.

```
{ \LayerRotation{view}{layer}{angle}{direction}  
  \RubikcubeFaceUpAll{Y}  
  ...  
  \DrawLayerRotation
```

Probably need to use \LaTeX to do all the calculations.



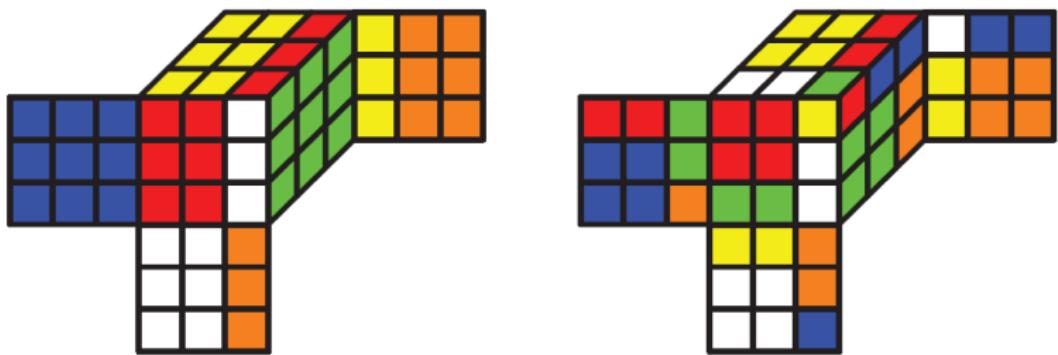
TODO

Raymond Tran³

			1	2	3							
			4	U	5							
			6	7	8							
9	10	11	17	18	19	25	26	27	33	34	35	
12	L	13	20	F	21	28	R	29	36	B	37	
14	15	16	22	23	24	30	31	32	38	39	40	
			41	42	43							
			44	D	45							
			46	47	48							

Flat representation of initial cube

³Tran R (2005). A mathematical approach to solving Rubik's cube.
www.math.ubc.ca/~cass/courses/m308/projects/rtran/rtran.pdf



⁴from Fig 4.2; IN: Rokicki T, Kociemba H, Davidson M and Dethridge J (2013). The diameter of the Rubik's cube is twenty. *SIAM. J. Discrete Math.*, 27, 1082–1105.

END

