26 Queens Road,

Loughton,

Essex.

13 July 1981.

Dear

Thank you for your letter asking for a copy of my

52-move strategy for solving Rubik's Cube. Please find

enclosed the following:-

(i) General instructions and description (3 pages);

(ii) Tables for Stage 2 (computer print-out);

(iii) Instructions and table for the first part of Stage 3;

(iv) Tables for the latter part of stage 3 (7 typewritten pages);

(v) Tables for Stage 4 (7 pages of computer print-out, photocopied).

I should perhaps point out that this strategy isn't

easy to perform (even John Conway finds it quite hard!),

for two reasons: first, only one representative of each

symmetry class is given in the tables; second, I have

given only the barest documentation. I hope that a fuller

description will be forthcoming at some stage.

On reading the bottom of page 2 of the General Instructions,

you will note that in fact Stage 2 requires two sets of

tables. I have omitted to send you the second of these,

because they are bulky, and only save one move! I hope you

will excuse this liberty. One can always get FU,FD,BU,BD

into the UD-slice (the middle horizontal slice) in at

most five moves in G1.

As an example of the strategy at work, consider the

position where the four upper corners are twisted clockwise,

the four lower corners are twisted antlclockwise, and all

twelve edges are flipped. Then the cube is restored by:-

Stage 1 DBFUR'L'D

Stage 2 L2F2D2F | L2R2F'R'BR2B'R'B'

Stage 3 L2B2 | U2LU2F2L2F2L'B2LB2L'

Stage 4 R2U2 | R2D2F2U2B2D2F2B2L2B2L2B2

Yours sincerely,

Morwen B. Thistlethwaite.

THE 45-52 MOVE STRATEGY

Introduction. Let G= <L,R,F,B,U,D> , G1= <L,R,F,B,U2,D2> ,

G2= <L,R,F2,B2,U2,D2> , G3= <L2,R2,F2,B2,U2,D2> . The plan is to

manoeuvre down through the chain G=G0> G1> G2> G3> 1. One gets from

Gi to Gi+1 by using moves in Gi only. In its shortest form this

strategy would be executed with the help of a computer, in which case

I conjecture only 45 moves would be needed, but here I have sacrificed

7 moves in order that there should be no need for a computer. With a

few more pages of tables, the figure 52 could be reduced to an

intermediate figure of, say, 49. I intend to do this shortly!

The indexes of the chain of subgroups are 2048, 1082565, 29400, 663552,

but these figures are considerably reduced by considering symmetries.

The reader may check that these indexes multiply together to give the

order of G. The accompanying tables are broadly classified according to

corner positions, and in detail according to edge positions. The words

listed actually produce the positions under consideration, so the

restoring moves are the inverses of these. In order to be able to use

the tables it is necessary to understand the basic characteristics of the

groups G1, G2, G3, so the necessary facts are presented below.

Getting into G1. This involves edge pieces only, and is easy, for which

reason no tables are given. An edge piece is BAD if in taking it home an odd

number of quarter-turns of U and D faces is needed; otherwise it is GOOD

(note that badness is well-defined). The reader may quickly work out a rule of

thumb for deciding whether a piece is GOOD or BAD. Now quarter-turns of

either U or D faces convert BAD pieces to GOOD and vice versa; other moves

have no effect. Therefore to make all edge pieces GOOD, move groups of them

to U or D face avoiding quarter-turns of U or D, and then cure them by

performing a quarter-turn of U or D. For example, if all twelve are BAD,

DBFUR'L'D will cure them all!

Getting from G1 into G2. What has been achieved so far (although

it doesn't look like it) is the correct orientation of edge pieces! In

the present stage, the same is accomplished for corners, and also the

edge pieces FU, FD, BU, BD are brought into their slice. As is well

known, corners do not in general have a natural orientation, but here,

roughly speaking, we shall line them all up the same way. More precisely,

note that each corner piece has either a L-facet or a R-facet: on

completion of this stage each of these facets will lie on either the L

or the R face. In fact, the same will be true of the eight edge pieces

with L or R facets, in view of the statement above regarding FU, FD, BU, BD.

There are 1082565 cases to consider here, this number being the product of

3^7(total number of corner orientations) , and 12C4 (total number of

arrangements of the set {FU, FD, BU, BD} amongst the twelve edge positions).

Surprisingly, with a certain amount of practice it is possible to get

through this stage in at most 17 moves without tables; the same is most

certainly not true of the next stage although there are only 29400 cases.

However, with a few pages of tables this figure of 17 may be reduced to 13;

with a great deal more computation, it should be possible to reduce it

further to 10. To "prove" that 10 moves were sufficient, one would run

through all 10-move sequences on the computer, and check that 1082565 different

cases resulted. This would take no more than a few hours of computer

time, in view of certain short cuts available by considering symmetries.

Now to business. The twist of a corner is measured by looking at its

L or R facet and observing how this has been rotated in relation to the

adjacent L or R face. Note that quarter-turns of F and B faces alter the

twist of corners, whereas all other moves in the group G1 have no effect.

Now in at most 4 moves in G1 *try to* obtain a position where ~~either the corners~~

~~on the F face or the corners on the B face have zero twist. Note the twist~~

~~of the corners on the opposite face and also the positiosn of the edge pieces~~

*the edge pieces FU, FD, BU, BD are all in the UD-slice. If this is not*

*possible, get them all in the U-face in at most 4 moves.*

~~FU, FB, BU, BD, and t~~*T*hen refer to the appropriate detailed table. The

words listed in these tables need to be inverted, as mentioned earlier.

Getting from G2 into G3. This is the trickiest stage theoretically,

and may be broken down for purposes of clarification into two sub-stages:

first get corners into their natural orbits, and second permute the

corners within their orbits so as to obtain one of the 96 corner permutations

in the squares group (G3), while at the same time sorting out the edge

pieces into their correct slices. The table of initial moves on the first

page of Stage 3 tables does part of the first of these substages, and the

detailed tables do the rest. After performing the initial moves, the set

of corners out of orbit will be one of three possibilities (modulo symmetries):

(i) the empty set; (ii) the set {1, 8, 2, 7} ; (iii) the set {1, 5} .

The reader then has to calculate which coset of form G3αβ the permutation

of corners lies in, where α is one of 1, (14)(68), (24)(58), (12), (14), (24),

and β is one of 1, (18)(27), (15). Since some of these cosets are reflections

of others, it was not necessary to produce tables for all six possible values

of α. The task of reflecting positions if necessary is left to the reader.

I apologise for the slightly anomalous numbering of edge positions for this

stage; this was due originally to a typing error in a programs and has

stuck ever since!

Getting from G3 to home. In this final stage one uses only 180 turns.

The order of G3 is 96x6912 = 663552. The tables for this stage give words

for producing each of the 6912 edge positions with corners fixed. Therefore

one must first restore the corners (in at most 4 moves), and then use the

tables to restore the edges. Considerable practice is needed to use these

tables efficiently, but I have found (after considerable practice) that I

can find the desired move in about 2 minutes. One hint is that when faced

with three 3-cycles, consider the configuration of the fixed pieces. Also

it pays to get to know the different sorts of 4-cycle.

STAGE 2 TABLES

FIRST BATCH OF NUMBERS: THE MOVES.

11=L 12=L2 13=L'

21=F 22=F2 23=F'

31=R 32=R2 33=R'

41=B 42=B2 43=B'

51=U2 52=D2

SECOND BATCH OF NUMBERS: TWISTS OF CORNERS.

1=CLOCKWISE 2=ANTICLOCKWISE 0=NO EFFECT

FINAL NUMBER: NUMBER OF SYMMETRICALLY EQUIVALENT POSITIONS.

N.B. FOR INITIAL 1X READ 21 1X.

21 11 31 22 11 31 51 52 21 0 0 0 0 0 0 0 0 1

21 11 33 42 11 51 33 52 21 0 0 0 1 0 0 2 0 4

21 11 22 51 52 12 22 33 21 0 0 0 1 1 0 2 2 8

21 11 22 31 43 51 13 22 11 0 0 0 1 1 1 2 1 8

21 11 52 11 21 31 52 41 51 0 0 0 1 2 2 0 1 8

21 11 22 12 52 12 52 31 41 0 0 0 2 0 1 2 1 8

11 21 33 23 11 32 51 52 23 0 0 1 0 0 0 2 0 4

11 21 33 23 11 32 51 52 21 0 0 1 0 2 0 0 0 4

11 42 31 21 13 42 33 41 51 0 0 1 1 0 0 2 2 2

21 11 21 33 42 11 23 12 43 0 0 1 1 0 1 0 0 8

21 11 22 31 41 11 32 42 13 0 0 1 1 1 0 1 2 8

21 11 31 21 51 31 21 41 11 0 0 1 1 2 2 0 0 2

21 11 22 32 41 51 13 22 11 0 0 1 1 2 2 2 1 8

21 11 21 41 11 23 41 11 43 0 0 1 2 0 0 0 0 8

21 11 41 51 41 12 42 11 41 0 0 1 2 0 0 1 2 4

21 11 42 12 41 52 41 11 41 0 0 1 2 0 0 2 1 4

21 11 21 32 42 11 23 12 43 0 0 1 2 0 1 0 2 8

21 11 22 12 22 51 31 52 21 0 0 1 2 1 0 0 2 8

21 11 21 12 23 42 11 43 12 0 0 1 2 1 0 1 1 8

21 11 22 13 21 31 21 11 41 0 0 1 2 1 1 0 1 8

21 11 21 41 11 23 43 11 43 0 0 1 2 2 1 0 0 4

21 11 22 11 52 33 51 21 51 0 0 2 0 0 0 0 1 4

21 11 22 11 22 52 33 51 23 0 0 2 0 0 0 1 0 4

21 11 22 11 52 33 51 21 12 0 0 2 0 0 1 0 0 4

21 11 22 11 22 52 33 51 21 0 0 2 0 1 0 0 0 4

21 11 33 42 11 21 12 31 43 0 0 2 1 1 0 0 2 8

21 11 22 13 21 13 21 12 43 0 0 2 1 1 1 2 2 8

21 11 21 11 52 11 23 11 43 0 0 2 2 0 0 1 1 2

21 11 22 11 32 52 33 51 23 0 0 2 2 0 0 2 0 8

21 11 23 11 33 51 21 12 43 0 0 2 2 2 0 0 0 8

21 11 51 31 23 52 12 21 33 0 1 0 0 0 2 1 2 8

21 11 22 51 52 12 22 33 23 0 1 0 0 2 0 1 2 8

21 11 52 11 21 31 52 41 12 0 1 0 0 2 1 0 2 8

21 11 32 43 12 31 43 51 31 0 1 0 0 2 2 2 2 8

21 11 21 43 11 31 21 51 31 0 1 0 1 2 0 1 1 8

21 12 22 51 52 31 22 32 21 0 1 0 1 2 0 2 0 2

11 23 41 31 41 11 33 52 21 0 1 0 1 2 2 0 0 8

21 11 22 12 51 31 52 21 12 0 1 0 2 0 0 1 2 8

21 11 32 51 43 52 33 23 12 0 1 0 2 0 2 0 1 4

11 22 11 51 41 11 52 23 51 0 1 0 2 1 0 2 0 4

21 11 42 51 41 11 33 23 33 0 1 0 2 2 1 2 1 8

21 11 51 33 41 33 21 51 11 0 1 0 2 2 2 0 2 8

11 22 51 43 11 33 21 42 11 0 1 1 0 0 2 0 2 8

12 22 51 52 31 22 32 21 31 0 1 1 0 2 0 0 2 2

21 11 21 43 11 31 21 51 33 0 1 1 0 2 0 1 1 8

21 11 22 31 41 13 22 13 22 0 1 1 0 2 1 0 1 8

21 11 51 43 31 21 42 51 11 0 1 1 0 2 1 2 2 8

21 11 21 33 51 41 11 21 51 0 1 1 1 1 0 1 1 8

11 21 11 43 33 43 51 13 23 0 1 1 1 1 0 2 0 8

11 22 12 21 32 51 52 31 21 0 1 1 1 2 0 2 2 4

21 11 21 12 42 31 23 11 43 0 1 1 2 0 0 1 1 8

21 11 32 23 11 51 52 21 51 0 1 1 2 0 2 0 0 8

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21 11 21 13 32 41 11 23 13 1 2 2 2 1 0 1 0 8

21 11 21 12 51 32 43 33 21 1 2 2 2 1 1 1 2 4

21 11 21 31 22 32 21 13 41 1 2 2 2 1 2 1 1 4

21 11 32 23 12 52 13 51 21 2 0 0 0 0 2 0 2 8

21 11 21 12 42 33 23 11 41 2 0 0 1 0 1 1 1 8

21 11 32 21 12 52 13 51 23 2 0 0 1 0 2 2 2 8

21 11 22 13 21 13 21 12 41 2 0 0 1 1 2 2 1 8

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21 11 22 42 51 21 51 13 41 2 0 0 1 2 2 1 1 8

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21 11 21 42 13 43 13 23 11 2 0 1 2 0 2 2 0 8

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21 11 21 42 31 23 13 43 51 2 0 1 2 2 0 1 1 8

21 11 22 11 21 42 13 32 43 2 0 1 2 2 0 2 0 8

21 11 21 43 11 23 43 11 43 2 0 1 2 2 1 0 1 8

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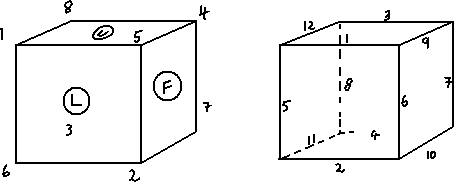
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STAGE 3: GETTING INTO THE SQUARES GROUP



Corners and edges are numbered as in the above diagrams.

Moves are coded as follows:

1=L, 2=L2, 3=L', 4=F2, 5=R, 6=R2, 7=R', 8=B2, 9=U2, 10=D2.

To accomplish stage 3, proceed as follows:

(i) Establish which corners are out of orbit.

(ii) Perform moves as indicated in the table below.

(iii) Find by calculation the right coset of the squares group

in which the permutation of corners now lies.

(iv) Refer to the appropriate detailed table. Find the numbers

of the positions of the four edge pieces of the FB-slice,

i.e. LU, LD, RU, RD. Find the number in the left-hand

column corresponding to these, and perform the inverse of

the given move. since some cosets are reflections of

others, the reader may have to undertake the extra task

of reflecting his position to find a suitable table.

CORNERS OUT OF ORBIT | INITIAL MOVE

1,5 | -

1,6 | -

1,7 | 4

1,8 | 2 9

1,2,5,6 | 1

1,2,5,7 | 1 4

1,2,5,8 | 3 9

1,2,7,8 | -

1,3,6,8 | 9

1,3,5,7 | 6 4

1,3,5,8 | 1 9

1,2,3.5,6,7 | 1

1,2,3,5,7,8 | 4 5

1,2,3,6,7,8 | 1 5 9

1,2,3,4,5,6,7,8 | 1 5

CORNERS OUT OF ORBIT: NONE COSET: G COSET: G(14)(68)

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1235 1 4 1 7 4 10 2 7 1 4 1 4 9 2 9 7 4 7

1236 1 4 1 7 4 10 7 8 1 4 1 4 2 9 1 8 10 7

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1257 1 4 1 4 8 3 10 7 1 4 1 4 2 9 1 10 5 4

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1248 1 4 3 4 9 7 4 9 7 9 7 1 4 1 4 1 4 2 8 2 6 9

1256 1 4 3 4 1 4 9 2 3 10 5 1 4 1 4 1 5 4 8 2 3 4

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page 6

CORNERS: (15). COSET: G(12) COSET: G(14)

1234 1 4 3 4 1 5 10 1 10 5 9 1 4 3 4 1 5 4 9 7 10 1

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1237 1 4 3 4 1 10 3 9 6 4 8 1 4 3 4 2 8 1 4 9 5 10

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1358 1 4 3 10 1 8 5 10 4 2

1367 1 4 3 9 2 8 9 3 10 3

1368 1 4 3 9 5 4 3 10 8 10

1378 1 4 3 9 5 10 8 5 9 10

1456 1 4 3 9 3 10 4 2 4 7

1457 1 4 3 10 1 6 10 6 9 1

1458 1 4 3 10 1 10 6 9 10 1

1467 1 4 3 10 4 9 10 3 8 5

1468 1 4 3 10 3 4 10 6 9 3

1478 1 4 3 10 4 6 10 3 4 7

1567 1 4 3 9 4 1 8 6 9 3

1568 1 4 3 9 4 2 1 10 8 3

1578 3 8 9 3 10 8 7 4 10 7

1678 1 4 9 1 10 4 5 8 10 5

2345 1 4 3 10 1 10 8 5 4 8

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2358 1 4 3 9 10 2 4 7 9 1

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2458 1 4 3 9 1 8 7 9 2 10

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2568 1 4 3 10 1 8 10 4 9 1

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4568 1 4 3 9 1 5 4 5 8 5

4578 1 4 3 9 4 9 4 7 9 1

4678 1 4 3 9 8 2 9 3 4 7

5678 1 9 10 8 3 9 4 3 9 1

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

KEY: 1=L; 2=F; 3=R; 4=B; 5=U; 6=D (ALL 180 DEGREE TURNS).

THE NUMBERS ON THE RIGHT GIVE THE PERMUTATION OF EACH SLICE.

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THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 1: AT LEAST ONE SLICE FIXED.

FB UD LR

1 2 1 2 1 2 1 2 1 2 1 2 1

1 2 1 2 1 2 1 2 1 3 4 3 (12) (34) 12

1 2 1 2 1 2 1 2 1 4 3 4 (12)(34) 6

1 2 1 2 1 2 1 2 3 2 1 4 (12)(34) (12)(34) 3

1 2 1 2 1 2 1 3 5 1 3 6 (12) (1324) 24

1 2 1 2 1 3 2 5 1 4 1 5 (12)(34) (123) 48

1 2 1 2 1 3 2 5 2 3 2 5 (1234) (12) 24

1 2 1 2 1 3 4 5 1 4 3 6 (123) 24

1 2 1 2 1 3 4 5 2 1 4 6 (24) (12) 24

1 2 1 2 1 5 1 2 5 2 1 5 (23) (12) 6

1 2 1 2 1 5 1 2 6 4 3 6 (14) (12) 6

1 2 1 2 1 5 2 1 2 5 2 1 (14) (12) 24

1 2 1 2 1 5 2 1 4 6 4 1 (1243) (12) 24

1 2 1 2 3 2 5 1 3 2 4 5 (1324) (1423) 12

1 2 1 2 3 5 1 4 5 4 3 6 (23) (1423) 24

1 2 1 2 4 1 2 1 5 1 3 6 (12)(34) (13)(24) 6

1 2 1 2 4 1 2 5 2 4 5 1 (14)(23) (14)(23) 6

1 2 1 2 4 1 4 1 5 1 3 5 (13)(24) (13)(24) 3

1 2 1 2 4 1 5 1 3 5 4 3 (13)(24) (12)(34) 6

1 2 1 2 4 3 2 5 6 3 5 6 (12)(34) (12)(34) 6

1 2 1 2 4 3 5 2 5 4 6 1 (1234) (12) 24

1 2 1 2 4 5 1 2 1 2 4 5 (13)(24) (134) 48

1 2 1 2 4 5 1 3 2 3 2 6 (1432) (1423) 24

1 2 1 2 4 5 1 4 1 2 4 6 (14)(23) (142) 48

1 2 1 2 4 5 2 5 3 4 6 1 (1234) (12) 24

1 2 1 2 5 1 3 6 4 3 2 1 (13)(24) 3

1 2 1 2 5 1 4 3 2 4 5 1 (1324) (24) 24

1 2 1 2 5 1 5 2 1 5 2 1 (13) (24) 12

1 2 1 2 5 1 5 2 5 2 1 5 (123) (142) 48

1 2 1 2 5 1 5 2 6 4 3 6 (134) (142) 48

1 2 1 2 5 2 1 5 1 2 5 2 (12) (13) 24

1 2 1 2 5 2 1 5 1 4 6 4 (1324) (13) 24

1 2 1 2 5 2 5 4 6 3 4 1 (1243) (12) 24

1 2 1 3 5 1 2 1 2 4 6 2 (1423) (1342) 24

1 2 1 3 5 1 2 5 2 3 5 3 (1324) (1432) 24

1 2 1 3 5 1 3 2 5 2 5 3 (1432) (1432) 12

1 2 1 5 2 5 1 5 1 2 5 2 (142) (123) 48

1 2 1 5 2 5 1 5 1 4 6 4 (243) (123) 48

2 1 2 1 3 5 1 2 5 2 3 5 3 2 (1324) (5867) 6

4 1 2 1 3 5 1 2 5 2 3 5 3 4 (1324) (5768) 6

End of execution.

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

KEY: 1=L; 2=F; 3=R; 4=B; 5=U; 6=D (ALL 180 DEGREE TURNS).

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THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 2: 3 3-CYCLES

FB UD LR

1 2 1 2 5 1 5 1 2 5 2 5 (124) (123) (142) 16

1 2 1 2 5 1 5 1 2 6 4 6 (124) (134) (142) 48

1 2 1 2 5 1 5 1 4 5 2 6 (132) (134) (142) 16

1 2 1 2 5 1 5 1 4 6 4 5 (132) (123) (142) 48

1 2 1 5 2 5 2 1 5 1 5 2 (142) (123) (142) 48

1 2 1 5 2 5 2 1 5 3 5 4 (123) (243) (134) 48

1 2 1 5 2 5 2 1 6 1 6 4 (123) (134) (134) 48

1 2 1 5 2 5 2 1 6 3 6 2 (142) (142) (142) 48

1 2 1 5 2 5 2 3 5 1 6 2 (142) (142) (123) 96

1 2 1 5 2 5 2 3 5 3 6 4 (123) (134) (243) 96

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

KEY: 1=L; 2=F; 3=R; 4=B; 5=U; 6=D (ALL 180 DEGREE TURNS).

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LR SLICE: 1=FU, 2=FD, 3=BD, 4=BU.

THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 3: NO SLICE FIXED; 2 3-CYCLES AND ONE DOUBLE TRANSPOSITION.

FB UD LR

1 2 1 2 5 1 5 2 5 4 1 6 (14)(23) (142) (134) 96

1 2 1 2 5 1 5 2 6 2 3 5 (14)(23) (243) (134) 96

1 2 1 2 5 1 5 4 5 4 3 5 (13)(24) (243) (134) 48

1 2 1 2 5 1 5 4 6 2 1 6 (13)(24) (142) (134) 48

1 2 1 5 2 5 1 5 3 2 6 2 (134) (243) (13)(24) 48

1 2 1 5 2 5 1 5 3 4 5 4 (123) (243) (13)(24) 48

1 2 1 5 2 5 2 1 2 6 3 6 (142) (12)(34) (142) 96

1 2 1 5 2 5 2 1 4 5 3 5 (123) (14)(23) (134) 96

End of execution.

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

KEY: 1=L; 2=F; 3=R; 4=B; 5=U; 6=D (ALL 180 DEGREE TURNS).

THE NUMBERS ON THE RIGHT GIVE THE PERMUTATION OF EACH SLICE.

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LR SLICE: 1=FU, 2=FD, 3=BD, 4=BU.

THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 4: NO SLICE FIXED; AT LEAST TWO DOUBLE TRANSPOSITIONS

FB UD LR

1 2 1 2 1 3 2 1 2 1 5 6 (13)(24) (13)(24) (14)(23) 6

1 2 1 2 1 3 2 1 2 5 6 3 (13)(24) (14)(23) (14)(23) 6

1 2 1 2 1 3 2 1 5 6 4 3 (13)(24) (12)(34) (14)(23) 3

1 2 1 2 1 3 2 3 4 3 5 6 (13)(24) (13)(24) (13)(24) 1

1 2 1 2 1 3 2 5 1 2 1 6 (13)(24) (13)(24) (243) 24

1 2 1 2 1 3 4 3 4 1 5 6 (14)(23) (13)(24) (14)(23) 3

1 2 1 2 1 3 4 3 4 5 6 3 (14)(23) (14)(23) (14)(23) 6

1 2 1 2 1 3 4 5 1 2 3 5 (14)(23) (13)(24) (243) 48

1 2 1 2 1 3 5 2 1 2 6 3 (234) (14)(23) (14)(23) 48

1 2 1 2 1 3 5 2 3 4 5 1 (234) (14)(23) (13)(24) 48

1 2 1 2 4 1 5 2 1 2 6 2 (243) (12)(34) (14)(23) 24

1 2 1 2 4 5 1 2 5 6 1 5 (12)(34) (12)(34) (142) 24

1 2 1 2 5 2 4 5 4 3 2 1 (12)(34) (14)(23) (14)(23) 2

1 2 3 4 5 2 1 2 1 3 5 1 (234) (14)(23) (12)(34) 24

End of execution.

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

KEY: 1=L; 2=F; 3=R; 4=B; 5=U; 6=D (ALL 180 DEGREE TURNS).

THE NUMBERS ON THE RIGHT GIVE THE PERMUTATION OF EACH SLICE.

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LR SLICE: 1=FU, 2=FD, 3=BD, 4=BU.

THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 5: NO SLICE FIXED; TWO 2-CYCLES.

FB UD LR

1 2 1 2 1 2 1 5 1 5 1 5 (12) (12) (124) 48

1 2 1 2 1 2 1 5 1 6 3 6 (12) (34) (124) 48

1 2 1 2 1 2 1 5 6 3 5 6 (12) (12)(34) (12) 24

1 2 1 2 1 2 5 1 3 2 4 6 (34) (13)(24) (34) 12

1 2 1 2 1 3 5 1 5 3 6 2 (12) (13) (123) 96

1 2 1 2 1 3 5 1 6 1 5 2 (12) (24) (123) 96

1 2 1 2 1 3 5 2 5 3 2 5 (124) (34) (12) 96

1 2 1 2 1 3 5 2 6 1 4 6 (124) (12) (12) 96

1 2 1 2 1 5 1 4 5 2 3 6 (12)(34) (14) (12) 12

1 2 1 2 1 5 1 4 6 4 1 5 (12)(34) (23) (12) 12

1 2 1 2 1 5 1 5 2 5 1 5 (12) (132) (12) 24

1 2 1 2 1 5 1 5 2 6 3 6 (12) (143) (12) 24

1 2 1 2 1 5 1 6 4 5 3 6 (12) (124) (12) 48

1 2 1 2 4 3 5 1 5 4 1 5 (12)(34) (14) (14) 24

1 2 1 2 4 5 1 2 5 3 6 1 (12)(34) (12) (24) 24

1 2 1 2 4 5 1 3 2 1 2 5 (13) (13)(24) (34) 24

1 2 1 2 4 5 1 5 3 6 4 1 (12)(34) (14) (24) 24

1 2 1 2 5 1 2 1 2 4 5 3 (34) (14)(23) (13) 24

1 2 1 2 5 1 5 4 3 6 4 1 (12)(34) (13) (24) 24

1 2 1 2 5 2 3 5 1 4 6 2 (12) (24) (12)(34) 24

1 2 1 3 2 5 2 1 5 1 4 6 (13)(24) (34) (34) 24

1 2 1 3 5 1 2 3 2 4 6 4 (12) (12)(34) (14) 24

1 2 1 3 5 1 2 5 4 1 5 1 (34) (24) (13)(24) 24

1 2 1 3 5 1 3 2 5 4 5 1 (13) (24) (13)(24) 12

1 2 1 3 5 1 5 1 2 1 4 6 (24) (23) (234) 96

1 2 1 3 5 1 5 3 2 1 2 6 (13) (23) (132) 96

1 2 1 5 1 5 1 2 5 2 5 1 (24) (132) (24) 48

1 2 1 5 1 5 1 2 6 4 6 1 (24) (234) (24) 48

1 2 1 5 2 1 5 1 4 6 4 1 (13)(24) (23) (12) 6

1 2 1 5 2 1 6 1 4 6 2 3 (13)(24) (14) (12) 6

End of execution.

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

KEY: 1=L; 2=F; 3=R; 4=B; 5=U; 6=D (ALL 180 DEGREE TURNS).

THE NUMBERS ON THE RIGHT GIVE THE PERMUTATION OF EACH SLICE.

THE ORDER IN WHICH SLICES ARE CONSIDERED IS FB,UD,LR.

FB SLICE: 1=LU, 2=LD, 3=RD, 4=RU.

UD SLICE: 1=LB, 2=LF, 3=RF, 4=RB.

LR SLICE: 1=FU, 2=FD, 3=BD, 4=BU.

THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 6: NO SLICE FIXED; TWO 4-CYCLES

FB UD LR

1 2 1 2 1 2 1 2 4 1 5 6 (1324) (13)(24) (1423) 12

1 2 1 2 1 2 1 2 4 5 6 3 (1324) (14)(23) (1423) 24

1 2 1 2 1 3 4 5 2 3 4 5 (1234) (13)(24) (1324) 24

1 2 1 2 1 3 5 1 2 1 6 3 (1423) (14)(23) (1432) 24

1 2 1 2 1 3 5 1 2 5 1 6 (1423) (1324) (243) 48

1 2 1 2 1 3 5 1 2 6 3 5 (1423) (1423) (243) 48

1 2 1 2 1 3 5 1 5 1 6 4 (1423) (1432) (243) 96

1 2 1 2 1 3 5 1 6 3 5 4 (1423) (1234) (243) 96

1 2 1 2 1 3 5 2 5 1 2 6 (234) (1324) (1324) 96

1 2 1 2 1 3 5 2 6 3 4 5 (234) (1423) (1324) 96

1 2 1 2 1 5 2 1 4 5 4 3 (1342) (12)(34) (1423) 24

1 2 1 2 3 5 1 2 5 2 1 6 (13)(24) (1243) (1324) 6

1 2 1 2 3 5 1 2 6 4 3 5 (13)(24) (1342) (1324) 6

1 2 1 2 3 5 1 4 5 2 3 5 (14)(23) (1342) (1324) 12

1 2 1 2 3 5 1 4 6 4 1 6 (14)(23) (1243) (1324) 12

1 2 1 2 3 5 1 5 2 5 1 6 (1423) (124) (1324) 48

1 2 1 2 3 5 1 6 4 5 3 5 (1423) (132) (1324) 24

1 2 1 2 3 5 1 6 4 6 1 6 (1423) (143) (1324) 24

1 2 1 2 4 3 5 1 2 1 6 4 (1423) (12)(34) (1342) 24

1 2 1 2 4 3 5 1 5 2 1 6 (13)(24) (1243) (1342) 24

1 2 1 2 4 5 1 5 1 6 2 1 (13)(24) (1342) (1234) 24

1 2 1 2 5 1 5 2 3 5 4 1 (14)(23) (1432) (1234) 24

1 2 1 2 5 1 5 4 1 6 2 1 (13)(24) (1432) (1234) 12

1 2 1 2 5 1 5 6 2 3 5 1 (1423) (12)(34) (1234) 24

1 2 1 2 5 2 3 5 3 2 6 4 (1423) (1234) (14)(23) 24

1 2 1 3 5 1 5 1 2 3 4 5 (1234) (1342) (143) 96

1 2 1 3 5 1 5 1 6 3 4 1 (14)(23) (1342) (1432) 24

1 2 1 3 5 1 5 3 2 3 2 5 (1432) (1342) (124) 96

1 2 1 5 1 5 3 2 5 4 6 1 (1432) (124) (1234) 48

1 2 1 5 1 5 3 2 6 2 5 1 (1432) (143) (1234) 48

End of execution.

MOVES IN THE SQUARES GROUP WHICH FIX CORNERS.

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THE NUMBER ON EXTREME RIGHT IS THE QUANTITY OF SYMMETRICALLY EQUIVALENT

POSITIONS

PAGE 7: NO SLICE FIXED; 2-CYCLE + 4-CYCLE.

FB UD LR

1 2 1 2 1 2 1 3 5 2 4 5 (34) (13)(24) (1423) 24

1 2 1 2 1 2 1 5 2 4 5 3 (34) (14)(23) (1423) 24

1 2 1 2 1 3 2 5 2 1 2 6 (24) (13)(24) (1324) 24

1 2 1 2 1 3 5 1 2 3 5 1 (1423) (14)(23) (24) 24

1 2 1 2 1 3 5 1 3 5 1 4 (1423) (14)(23) (34) 24

1 2 1 2 1 5 1 2 5 4 1 6 (14)(23) (1342) (34) 24

1 2 1 2 1 5 1 3 2 5 4 6 (143) (1342) (34) 96

1 2 1 2 1 5 1 3 2 6 2 5 (143) (1243) (34) 96

1 2 1 2 1 5 1 4 5 4 3 5 (13)(24) (1243) (34) 24

1 2 1 2 1 5 1 5 4 5 3 5 (1423) (124) (34) 48

1 2 1 2 1 5 1 5 4 6 1 6 (1423) (234) (34) 48

1 2 1 2 1 5 1 6 2 5 1 6 (1423) (132) (34) 48

1 2 1 2 1 5 1 6 2 6 3 5 (1423) (143) (34) 48

1 2 1 2 1 5 2 1 2 6 2 3 (23) (12)(34) (1423) 24

1 2 1 2 4 1 5 1 2 1 6 2 (1324) (12)(34) (14) 24

1 2 1 2 4 1 5 1 5 4 3 5 (13)(24) (1243) (14) 24

1 2 1 2 4 1 5 2 3 5 2 5 (1234) (23) (12)(34) 24

1 2 1 2 4 1 5 2 5 2 5 3 (1234) (24) (12)(34) 24

1 2 1 2 4 3 5 2 5 2 6 3 (24) (1234) (13)(24) 24

1 2 1 2 4 5 1 5 1 5 2 3 (12)(34) (14) (1432) 24

1 2 1 2 4 5 1 5 3 5 4 3 (13)(24) (1342) (13) 24

1 2 1 2 4 5 2 5 1 4 5 1 (24) (1324) (14)(23) 24

1 2 1 2 4 5 2 5 6 1 2 5 (1234) (12)(34) (12) 24

1 2 1 2 4 5 2 5 6 3 2 6 (24) (14)(23) (1324) 24

1 2 1 2 5 1 3 2 5 1 4 5 (132) (12) (1423) 96

1 2 1 2 5 1 3 2 5 3 4 6 (143) (1423) (34) 96

1 2 1 2 5 1 3 2 6 1 2 5 (143) (1324) (34) 96

1 2 1 2 5 1 3 2 6 3 2 6 (132) (34) (1423) 96

1 2 1 2 5 1 5 1 2 4 6 4 (1324) (13) (142) 96

1 2 1 2 5 1 5 1 6 4 5 6 (12) (1234) (142) 96

1 2 1 2 5 1 5 3 2 4 6 2 (34) (1432) (134) 96

1 2 1 2 5 1 5 3 6 2 5 6 (1423) (24) (134) 96

1 2 1 2 5 1 5 6 4 1 5 3 (12) (13)(24) (1432) 24

1 2 1 2 5 2 1 5 3 2 6 2 (34) (1432) (13)(24) 24

1 2 1 2 5 2 5 2 6 1 4 1 (23) (1423) (14)(23) 24

1 2 1 3 5 1 2 1 6 2 5 6 (34) (14)(23) (1342) 24

1 2 1 3 5 1 2 3 6 4 5 6 (1324) (13)(24) (14) 24

1 2 1 3 5 2 5 2 5 3 5 6 (1234) (13) (14)(23) 24

1 2 1 5 1 5 1 2 4 5 4 3 (12)(34) (1243) (13) 24

1 2 1 5 1 5 1 2 5 4 5 3 (1234) (124) (13) 96

1 2 1 5 1 5 1 2 6 2 6 3 (1234) (143) (13) 96

1 2 1 5 1 5 2 5 2 3 6 3 (12) (132) (1432) 96

1 2 1 5 1 5 2 5 4 3 5 3 (1423) (124) (13) 96

1 2 1 5 1 5 2 6 2 1 6 3 (1423) (143) (13) 96

1 2 1 5 1 5 2 6 4 1 5 3 (12) (234) (1432) 96

1 2 1 5 1 5 3 6 2 5 6 1 (14)(23) (14) (1234) 24

A DETAILED EXAMPLE OF THE 52-MOVE STRATEGY

(UFL)+ (URF)- (UBR)+ (ULB)- (LF)\* (FR)\* (RB)\* (BL)\*

First decide on a coordinate system for the Cube

(i.e. decide which colours are L,R,F,B,U,D); then get

it into the above position.

Stage 1. There are 4 bad edge-pieces, namely in positions

LF,FR,RB,BL. Manoeuvre these to the U-face by FLR'D2B2.

Then the move U corrects them.

Summary of Stage 1:- FLR'D2B2U (6 moves).

Stage 2. The LR-slice edge pieces are now in positions

LD,FD,RD,BD. Manoeuvre these to the UD-slice by F2D2LR'F.

Now taking the corner positions in order (as in the

diagram in Stage 3 instructions), the respective twists of

the pieces in these positions are 0,2,0,2,0,0,1,1. This

combination of twists is not given in Stage 2 tables, but

a 180° rotation about the LR-axis followed by reflection

in the LR-slice transforms this to 2 2 0 0 0 1 0 1, which

is in the tables. The move given is F LFL2F'LF2BL2, and

transforming this by the above (involutory) symmetry gives

B'R'B'R2BR'B2F'R2. Therefore we perform the inverse of

this move, after which L and R faces have L and R colours

on them only.

Summary of Stage 2:- F2D2LR'FR2FB2RB'R2BRB (14 moves)

Stage 3. The positions where corners are out of orbit are

numbers 1,2,5,8. The preliminary instructions for this

stage instruct us to perform L'U2. For the remainder of

this stage alter the coordinate system so that the original

D-face faces you and the original F-face faces upwards.

In this new coordinate system the positions where corners

are out of orbit are 1,5. The permutation of corners is

(1357)(24). Multiplying this on the right by (15)(24) gives

(13)(57) which is a permutation of corners in G3. Therefore

we must refer to page 7 of the Stage 3 tables. The edge-

pieces of the FB-slice are in positions 3,4,5,8. The tables

give us LF2L'U2LF2R2F2B2R, or LD2L'F2LD2R2D2U2R in the

original coordinate system. Perform the inverse of this move.

Summary of Stage 3:- L'U2R'U2D2R2D2L'F2LD2L' (12 moves).

Stage 4. The corners are restored by L2R2(original coordinates).

Looking at edge-pieces, as no slice is fixed and there is

a 2-cycle and a 4-cycle, we refer to page 7 of the Stage 4

tables. The only entries where the correct arrangement of

pieces is permuted and the 4-cycle is of the correct type are

(143) (1342) (34) and (143) (1243) (34). If we hold the

Cube with the original R-face facing the operator, and the

original B-face uppermost, we find we have the second of these

permutations. Therefore perform the inverse of the move

given, i.e. perform B2R2F2R2D2U2B2U2R2U2R2U2in original coords.

Summary of Stage 4:- L2R2B2R2F2R2D2U2B2U2R2U2R2U2(14 moves).

Total number of moves required: 6+14+12+14 = 46. (45 with cancellation)

M.B.T.