Two Two-Cycles

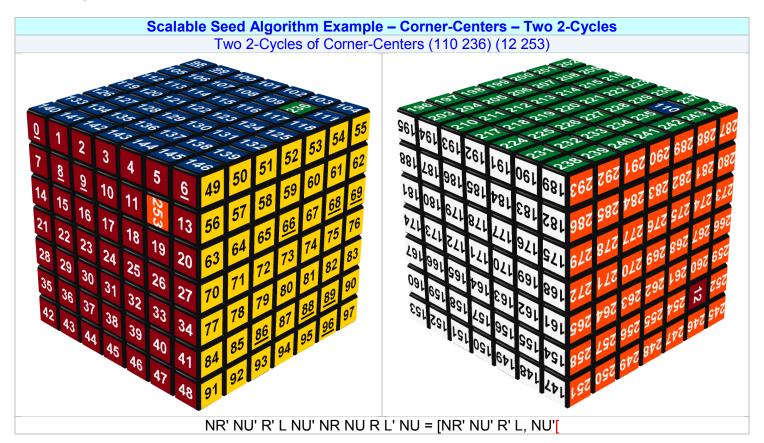
Two 2-cycles are particular permutations of cube pieces where 4 pieces are permuted 2 by 2. Two 2-cycles are even-parity permutations. They can be represented as the composition of two transpositions (i j) (k l).

From group theory, it is known that any permutation of a group can be expressed as the composition (product) of transpositions – formally, they are *generators* for the group. In an *alternating* group, all permutations are of *even* parity and thus can be expressed as the composition of an *even* number of transpositions. They can be further grouped 2 by 2 to give a set of two 2-cycles only, without any single transposition left aside. This shows that *any* member of an alternating group can be generated by using two 2-cycles only, hence the importance of generating a *complete* database of (possibly short) algorithms of two 2-cycles.

Short algorithms of two 2-cycles of pieces can be found by running algorithm templates in the VBA version of Algorithm Finder to give *seeds*. A seed algorithm is defined as a *short* algorithm that could generate a set of many other algorithms, by rotation/reflection, inversion, cyclic-shifting, or by adding setup moves. Seed algorithms are *irreducible*, meaning that they can't be obtained from each other by inversion, cyclic-shifting or symmetry considerations. See <u>http://www.mementoslangues.fr/CubeDesign/CubeTheory/SeedAlgorithms.pdf</u> for more information.

Seed algorithms are sorted out in stacks, where the first selected items are the shortest algorithms found. Each selected seed algorithm in the stack is then transformed by rotation/reflection, inversion and cycle shifting. Setup moves may be further added before algorithm execution and comparison of the new cube state with a goal state. If the two states are identical, then the transformed algorithm is added to the database. This is continued until the database is complete. Stacks of *scalable* seed algorithms have been generated for two 2-cycles of:

- Corners
- Midges
- Edges
- Corner-Centers
- Midge-Centers
- Edge-Centers



| Group Theory – Useful Links |
|--|
| http://en.wikipedia.org/wiki/Permutation |
| http://en.wikipedia.org/wiki/Symmetric_group |
| http://en.wikipedia.org/wiki/Conjugacy_class |
| http://groupprops.subwiki.org/wiki/Cycle type of a permutation |
| http://en.wikipedia.org/wiki/Coset |

By applying basic group theory to the cube, it can be inferred that (see links above for more details):

Conjugacy Class:

If A is an algorithm that generates a permutation of a given cycle type, then conjugate B A B' is also an algorithm that will generate another permutation of the *same* cycle type. This means that conjugating an algorithm will *not* change the cycle type of the associated permutation, or more explicitly if A generates a 7-cycle of corner-centers, then B A B' will also generate a 7-cycle of corner-centers. This is a very simple means of building a set of algorithms of a given cycle type from an already known 'seed' algorithm. The operation of conjugating an algorithm is also known as 'setup'. In most practical cases, setup moves are 1-, 2- or 3-move long. By using a set of different seed algorithms, it is possible to lower the number of needed setup moves from 3 to 2 or even 1.

Coset:

If A is an algorithm that generates a permutation of a given cycle type, then B A is also an algorithm that will generate another permutation, but which is generally of a *different* cycle type, although permutations of a same cycle type *may* be generated in *some* cases. This means that by inserting moves at the left, algorithms of a same cycle type *may* eventually be generated. Left added algorithms are usually 1-, 2- or 3-move long.

Symmetry:

If A is an algorithm that generates a permutation of a given cycle type, then transformed algorithm B(A), obtained by applying (anti)symmetry transformations on the set of letters <F, R, U, L, D, B> is also an algorithm that will generate another permutation of the *same* cycle type. This means that transforming an algorithm using all 48 possible cube (anti)symmetries will *not* change the cycle type of the associated permutations, or more explicitely if A generates a 5-cycle of edge-centers, then 48 more algorithms may be obtained by transforming letters.

Inversion:

If A is an algorithm that generates a permutation of a given cycle type, then inverted algorithm A' is also an algorithm that will generate another permutation of the *same* cycle type. This means that for each already known algorithm, one more can be added simply by inversion.

Cycle Shifting:

If A is an algorithm of length n that generates a permutation of a given cycle type, then the n algorithms obtained by cycle shifting A will also generate permutations of the *same* cycle type. Alg NR' U N3R U' NR U N3R' U' and the shifted version U' NR' U N3R U' NR U N3R' will *both* give a 3-cycle of edge-centers, for example.

Using a combination of all these techniques, ie. conjugation + left add + symmetry + inversion + cycle shifting, it is usually possible to generate many N-cycles of a given type from just a *limited* number of seed algorithms. The problem now is how to find *short* and *irreducible* seeds. This is where algorithm templates may come into play...

Semi-Commutators

Overview

It has already been demonstrated that all permutations of even parity can be written as commutators. But a more general way of describing a permutation of even parity would be as follows :

A (B C B')

where A, B and C are *multiple* move sequences, (B C B') is a conjugator and C is a function of A.

If C = A', then this expression gives the well-known commutator A B A' B' = [A, B]. We can go further by stating that C can also be a function of A, provided that the parity of the permutation is kept even. By decomposing A into a sequence of n basic moves:

sequence C can then be written as:

C = C1 C2 C3 ... Cn

There are now 2 possible cases that will keep parity:

C = An' ... A3' A2' A1' C = A1' A2' A3' ... An'

In the first case, we have the well-known commutator:

(A1 A2 A3 ... An) . B . (An' ... A3' A2' A1') . B' = [A, B]

whereas in the second case, it is a *semi*-commutator:

(A1 A2 A3 ... An) . B . (A1' A2' A3' ... An') . B' =]A, B]

There are just 4 ways of writing a semi-commutator:

(A1 A2) . (B1 B2) . (A1' A2') . (B2' B1') =]A1 A2, B1 B2] (A1 A2) . (B1 B2) . (A1' A2') . (B1' B2') =]A1 A2, B1 B2[(A1 A2) . (B1 B2) . (A2' A1') . (B1' B2') = [A1 A2, B1 B2[(A1 A2) . (B1 B2) . (A2' A1') . (B2' B1') = [A1 A2, B1 B2]

We can see that semi-commutator #4 is actually a commutator, so that a semi-commutator may simply be seen as an attempt to generalize the commutator concept.

Example

Semi-commutators may be useful for finding algorithms. Using for example a template such as]X Y, Z P Q P'] to search for 15-cycles of corner-centers, will give the algorithm below, which is clearly not a commutator:

]NR' NF', NL L' ND L] = NR' NF' . NL L' ND L . NR NF . L' ND' L NL'

But if it is written as a commutator, then we have a 9-cycle of corner-centers:

[NR' NF', NL L' ND L] = NR' NF' . NL L' ND L . NF NR . L' ND' L NL'

Block Decomposition

Another way of understanding semi-commutators is from block decomposition of a sequence of moves. Consider for example a first block of n moves followed by a second block of the same length: there must be the same number of moves and inverted moves in the complete sequence of 2 blocks, in order to keep the permutation parity even. There are many ways of re-arranging moves and inverted moves in the sequence. In a simple arrangement, all non-inverted moves are placed in the first block and all inverted moves in the second block:

First block: A1 A2 A3 ... An

Second block: same moves, but inverted, sequenced and partitioned differently

By using semi-commutators, there are just 4 different ways of re-arranging inverted moves in the second block.

This is shown in the table below, where a sequence of length 14 has been chosen and possible semicommutator structures are listed.

| | Block partitioning – Se | emi-Commutators – 14-Move Sequ | ence Example |
|-------|-------------------------|--------------------------------|------------------------------|
| Index | First Block of Moves | Second Block of Inverted Moves | Semi-Commutators/Commutators |
| 1 | (X Y Z P Q V A) | (X' Y' Z' P' Q' V' A') | [X, Y Z P Q V A[|
| | | | |
| 2 | (X) (Y Z P Q V A) | (X') (Y' Z' P' Q' V' A') | [X, Y Z P Q V A[|
| 3 | (X) (Y Z P Q V A) | (X') (A' V' Q' P' Z' Y') | [X, Y Z P Q V A] |
| | | | |
| 4 | (X Y) (Z P Q V A) | (X' Y') (Z' P' Q' V' A') |]X Y, Z P Q V A[|
| 5 | (X Y) (Z P Q V A) | (X' Y') (A' V' Q' P' Z') |]X Y, Z P Q V A] |
| 6 | (X Y) (Z P Q V A) | (Y' X') (Z' P' Q' V' A') | [X Y, Z P Q V A[|
| 7 | (X Y) (Z P Q V A) | (Y' X') (A' V' Q' P' Z') | [X Y, Z P Q V A] |
| | | | |
| 8 | (X Y Z) (P Q V A) | (X' Y' Z') (P' Q' V' A') |]X Y Z, P Q V A[|
| 9 | (X Y Z) (P Q V A) | (X' Y' Z') (A' V' Q' P') |]X Y Z, P Q V A] |
| 10 | (X Y Z) (P Q V A) | (Z' Y' X') (P' Q' V' A') | [X Y Z, P Q V A[|
| 11 | (X Y Z) (P Q V A) | (Z' Y' X') (A' V' Q' P') | [X Y Z, P Q V A] |

Semi-commutator #6 is then written as:

[X Y, Z P Q V A[= X Y . Z P Q V A . Y' X' . Z' P' Q' V' A'

Whereas commutator #7 would read:

[X Y, Z P Q V A] = X Y . Z P Q V A . Y' X' . A' V' Q' P' Z'

Usefulness

Semi-commutators are mainly used in searching for new algorithms and building arrays of seeds. For permutations involving more than 3 pieces, templates built on semi-commutators will usually give additional algorithms that will complement algorithms already found using commutators only.

Algorithm Templates

| Algorithm Templates – | Corners Two 2-Cycles | |
|--|------------------------------------|-------|
| Template | | Moves |
| [X, Y Z P Q V] | | 12 |
| [X, Y Z P Q V | | 12 |
| (X Y Z P Z' Y')2 X | 2 | 13 |
| (X Y Z P Y' Z')2 X | 2 | 13 |
| (X Y X') Z (X Y' X') (P Q P') | Z' (P Q' P') | 14 |
| | 18 Moves in Set | |
| <r, f',="" f,="" f2<="" r',="" r2,="" td="" u',="" u,="" u2,=""><td>, L, L', L2, D, D', D2, B, B', B2></td><td></td></r,> | , L, L', L2, D, D', D2, B, B', B2> | |
| Number of Permuted Pieces | Permutation Order | |
| 4 | 2 | |

| Algorithm Templates - | - Midges Two 2-Cycles | |
|--|-------------------------------------|--------|
| Template | | Moves |
| [X, Y Z P Q] | | 10 |
| [X, Y Z P Q[| | 10 |
| [X, Y Z P Z' Y'] | | 12 |
| [X, Y Z P Y' Z'] | | 12 |
| [X, Y Z P Z' Y'[| | 12 |
| [X, Y Z P Y' Z'] | | 12 |
| Set of Moves – | 36 Moves in Set | |
| <r, f',="" f,="" f2<="" r',="" r2,="" td="" u',="" u,="" u2,=""><td>2, L, L', L2, D, D', D2, B, B', B2,</td><td></td></r,> | 2, L, L', L2, D, D', D2, B, B', B2, | |
| MR, MR', MR2, MU, MU', MU2, MF, MF', MF2, | ML, ML', ML2, MD, MD', MD2, MB, MB' | , MB2> |
| Number of Permuted Pieces | Permutation Order | |
| 4 | 2 | |

| Algorithm Templates | – Edges Two 2-Cycles | |
|---|--|-------|
| Template | | Moves |
| [X, Y Z P Z' Y'] | | 12 |
| [X, Y Z P Y' Z'] | | 12 |
| [X, Y Z P Z' Y'] | | 12 |
| [X, Y Z P Y' Z'] | | 12 |
| (X Y Z P Z' Y')2 X | 2 | 13 |
| (X Y Z P Y' Z')2 X | 2 | 13 |
| (X Y X') Z (X Y' X') (P Q P') | Z' (P Q' P') | 14 |
| Set of Moves – 36 Move | s in Set | |
| <r, f',="" f,="" f2<="" r',="" r2,="" td="" u',="" u,="" u2,=""><td>, L, L', L2, D, D', D2, B, B', B2,</td><td></td></r,> | , L, L', L2, D, D', D2, B, B', B2, | |
| NR, NR', NR2, NU, NU', NU2, NF, NF', NF2, | NL, NL', NL2, ND, ND', ND2, NB, NB', N | VB2> |
| Number of Permuted Pieces | Permutation Order | |
| 4 | 2 | |

| Algorithm Templates – Co | rner-Centers Two 2-Cycles | |
|---|--|-------|
| Template | | Moves |
| [X, Y Z P] | | 8 |
| [X, Y Z P[| | 8 |
| [X, Y Z P Q] | | 10 |
| [X, Y Z P Q[| | 10 |
| Set of Moves – | 36 Moves in Set | |
| <r, f',="" f,="" f2<="" r',="" r2,="" td="" u',="" u,="" u2,=""><td>, L, L', L2, D, D', D2, B, B', B2,</td><td></td></r,> | , L, L', L2, D, D', D2, B, B', B2, | |
| NR, NR', NR2, NU, NU', NU2, NF, NF', NF2, | NL, NL', NL2, ND, ND', ND2, NB, NB', M | VB2> |
| Number of Permuted Pieces | Permutation Order | |
| 4 | 2 | |

| Algorithm Templates – Mi | idge-Centers Two 2-Cycles | |
|--|--|---------|
| Template | | Moves |
| [X, Y] | | 4 |
| [X, Y Z] | | 6 |
| [X, Y Z | | 6 |
| Set of Moves – | 48 Moves in Set | |
| <r, f',="" f,="" f2<="" r',="" r2,="" td="" u',="" u,="" u2,=""><td>2, L, L', L2, D, D', D2, B, B', B2,</td><td></td></r,> | 2, L, L', L2, D, D', D2, B, B', B2, | |
| MR, MR', MR2, MU, MU', MU2, MF, MF', MF2 | , ML, ML', ML2, MD, MD', MD2, MB, MB | ', MB2, |
| NR, NR', NR2, NU, NU', NU2, NF, NF', NF2, | , NL, NL', NL2, ND, ND', ND2, NB, NB', N | VB2> |
| Number of Permuted Pieces | Permutation Order | |
| 4 | 2 | |
| | · | |
| Algorithm Templates – E | dge-Centers Two 2-Cycles | |
| Template | | Moves |
| | | 0 |

| Template | | Moves |
|--|--------------------------------------|-----------------|
| [X, Y Z P] | | 8 |
| [X, Y Z P[| | 8 |
| [X, Y Z P Q] | | 10 |
| [X, Y Z P Q | | 10 |
| Set of Moves – | 48 Moves in Set | |
| <r, f',="" f,="" f2<="" r',="" r2,="" td="" u',="" u,="" u2,=""><td>2, L, L', L2, D, D', D2, B, B', B2,</td><td></td></r,> | 2, L, L', L2, D, D', D2, B, B', B2, | |
| NR, NR', NR2, NU, NU', NU2, NF, NF', NF2, | NL, NL', NL2, ND, ND', ND2, NB, NB', | NB2, |
| N3R, N3R', N3R2, N3U, N3U', N3U2, N3F, N3F', N3F2, | N3L, N3L', N3L2, N3D, N3D', N3D2, N3 | 3B, N3B', N3B2> |
| Number of Permuted Pieces | Permutation Order | |
| 4 | 2 | |

Algorithm Finder

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| R2 NU R2 NB2 R2 NU' R2 NB2 | | | | 3 | 8 | 4 | 2 | 6 | |
| R2 NU R2 NF2 R2 NU' R2 NF2 R2 NU2 R2 NF R2 NU2 R2 NF' | | | | 4 | 8 | 4 | 2 | 6 6 | |
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| R' NU' R2 NF2 R2 NU R2 NF2 R' R' NU2 R2 NB' R2 NU2 R2 NB R' | | | | 12 | | 4 | 2 2 | 6 6 | |
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| IR2 U NL' NB2 U' NR2 U NB2 NL U' IR2 U NL2 NB U' NR2 U NB' NL2 U' | | | | 25 | | 4 | 2 | 6 6 | |
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