Human Strategy based Evolutionary Cube Solver

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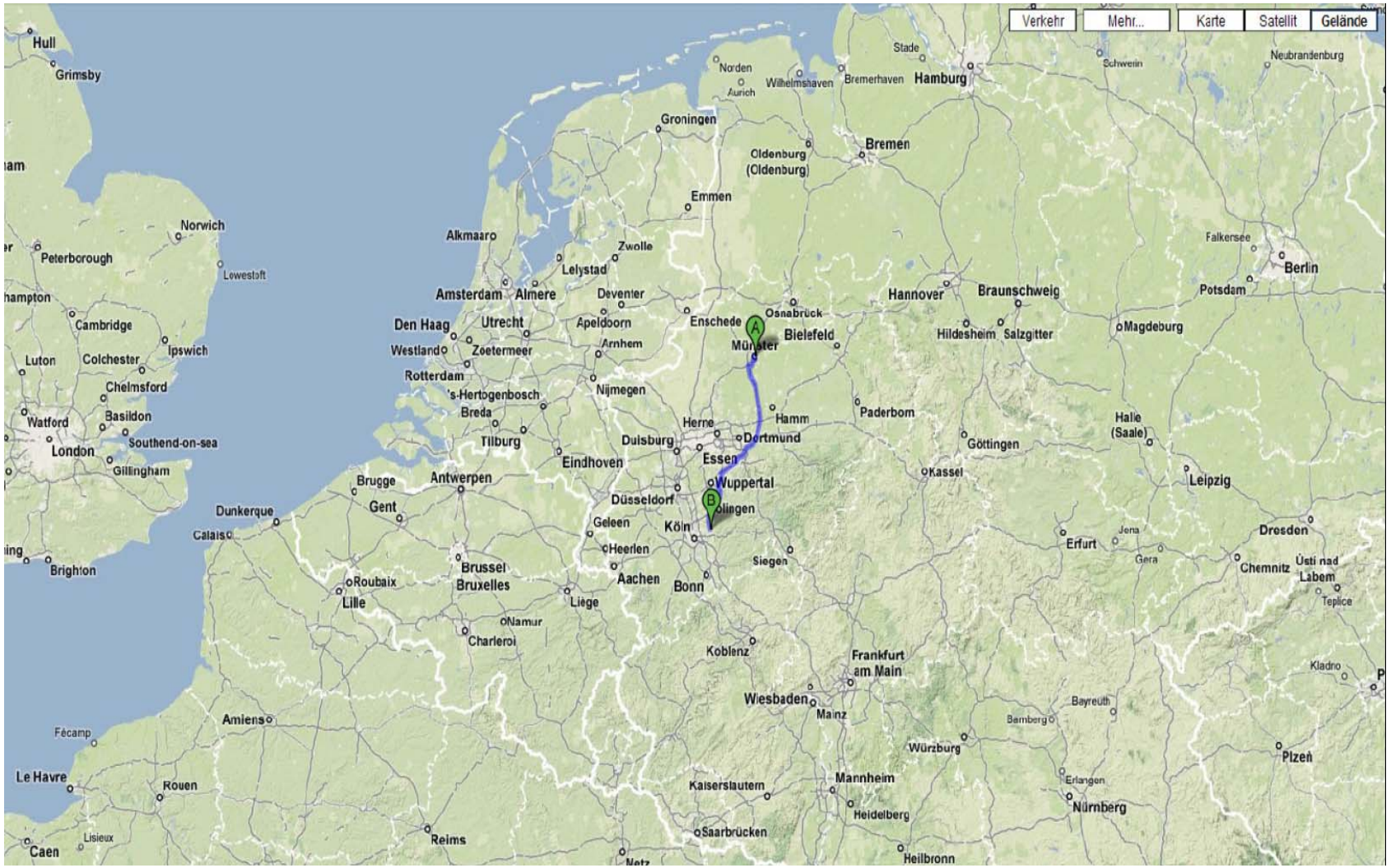

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1. Introduction
2. What exactly is the contribution ?
3. Why does the result qualify as being human-competitive ?
4. Conclusion:

Why is this the "best" entry in comparison to others ?

5. HuGO! “live”

• N. El-Sourani, S. Hauke, M. Borschbach, "An Evolutionary Approach for Solving the Rubik's Cube Incorporating Exact Methods",
In C. Di Chio et al. (Eds.): EvoApplications 2010, Part I, LNCS 6024, pp. 80–89, 2010, Springer-Verlag Berlin Heidelberg 2010.

• N. El-Sourani, M. Borschbach, "Design and Comparison of two Evolutionary Approaches for Solving the Rubik's Cube", to appear PPSN 2010.

• M. Borschbach, C. Grelle, "Empirical Benchmarks of a Genetic Algorithm Incorporating Human Strategies", Technical Report no. 2009/01, University of Applied Sciences, Bergisch Gladbach, April 2009. http://www.fhdw.de/Borschbach.aspx

✓ Satisfies regulation „D" of the humies award:

• **D**: The result is publishable in its own right as a new scientific result.

www.youtube.com

✓ Satisfies regulation „E“ of the humies award:

- **E**: ….equal or better than the most recent human-created .. a long-standing problem for which there has been a succession of increasingly better human-created solutions.

Contestants of cube competition use particular „human“ strategies to solve the cube

- **Idea:**

  Take human strategies and incorporate them into an evolutionary approach.

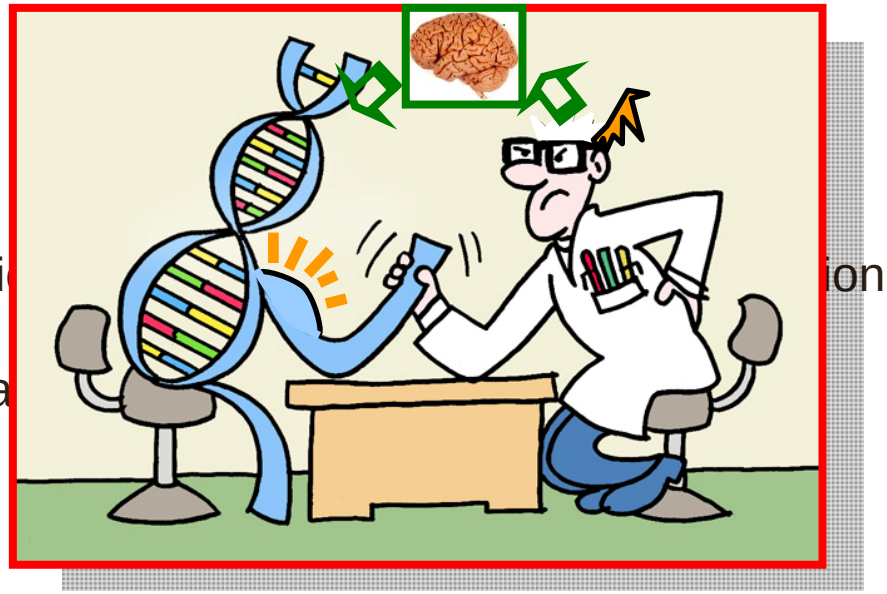
  Use group theoretical background to reduce complexity.

- **Result:**

  A more powerful evolutionary algorithm adapting human strategies and incorporating exact approaches.

  → **Symbiotic Intelligence**

Contestants of cube competition use particular „human“ strategies to solve the cube



- **Idea:**

  Take human strategi ionary approach

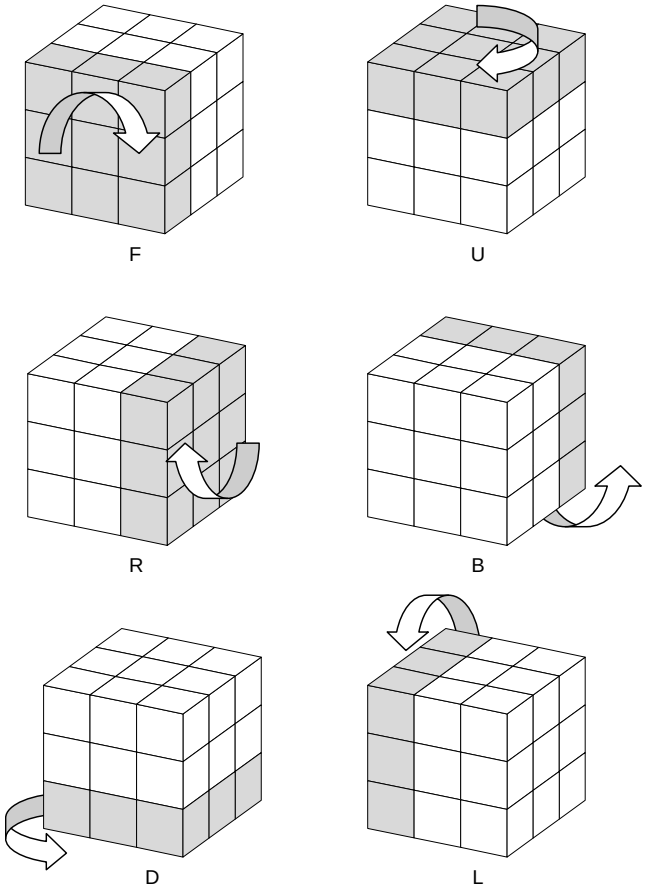
  Use group theoretica

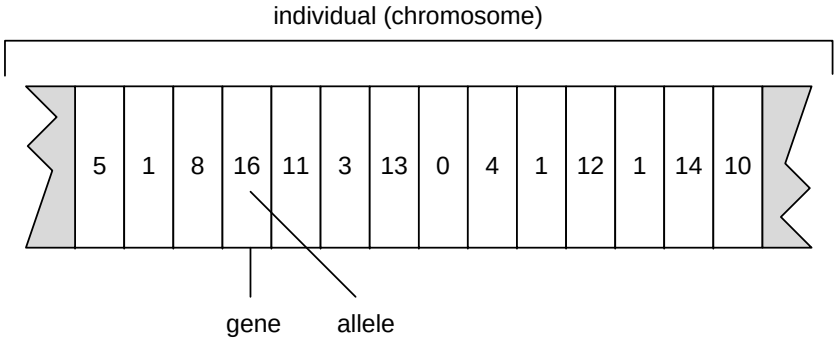
- **Result:**

  A more powerful evolutionary algorithm adapting human strategies and incorporating exact approaches.

  → **Symbiotic Intelligence**

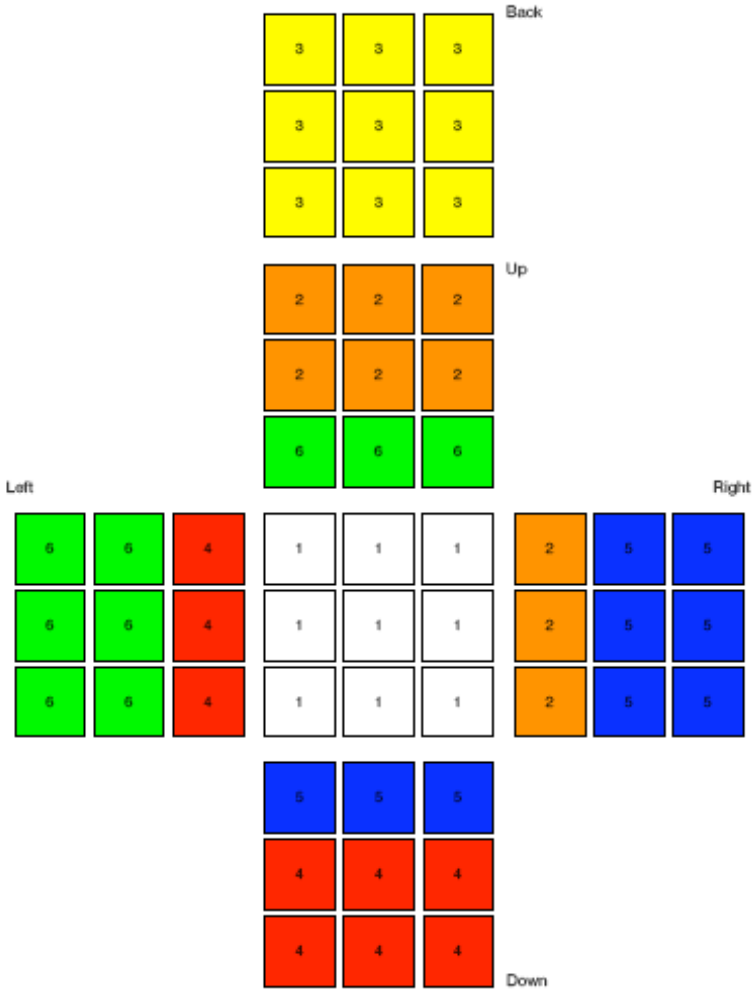
- HuGO!: Human strategy based Genetic Optimizer

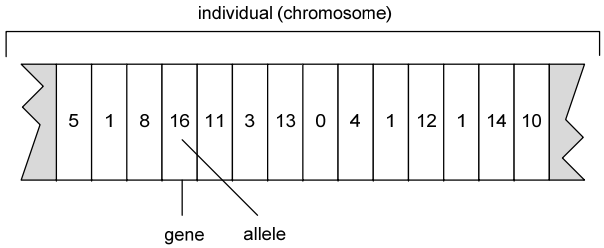




Clockwise quarter turns		Half turns		Counter-clockwise quarter turns	
F	0	F2	6	F’	12
U	1	U2	7	U’	13
R	2	R2	8	R’	14
B	3	B2	9	B’	15
D	4	D2	10	D’	16
L	5	L2	11	L’	17

- represented using 6 2D matrices
- can be mutated only by applying move sequences
- remembers all mutations it has undergone as a sequence list
- automatically removes redundant moves after each mutation
- remembers optimized sequence only
- Example: $F \cdot FRRiB = F2B$





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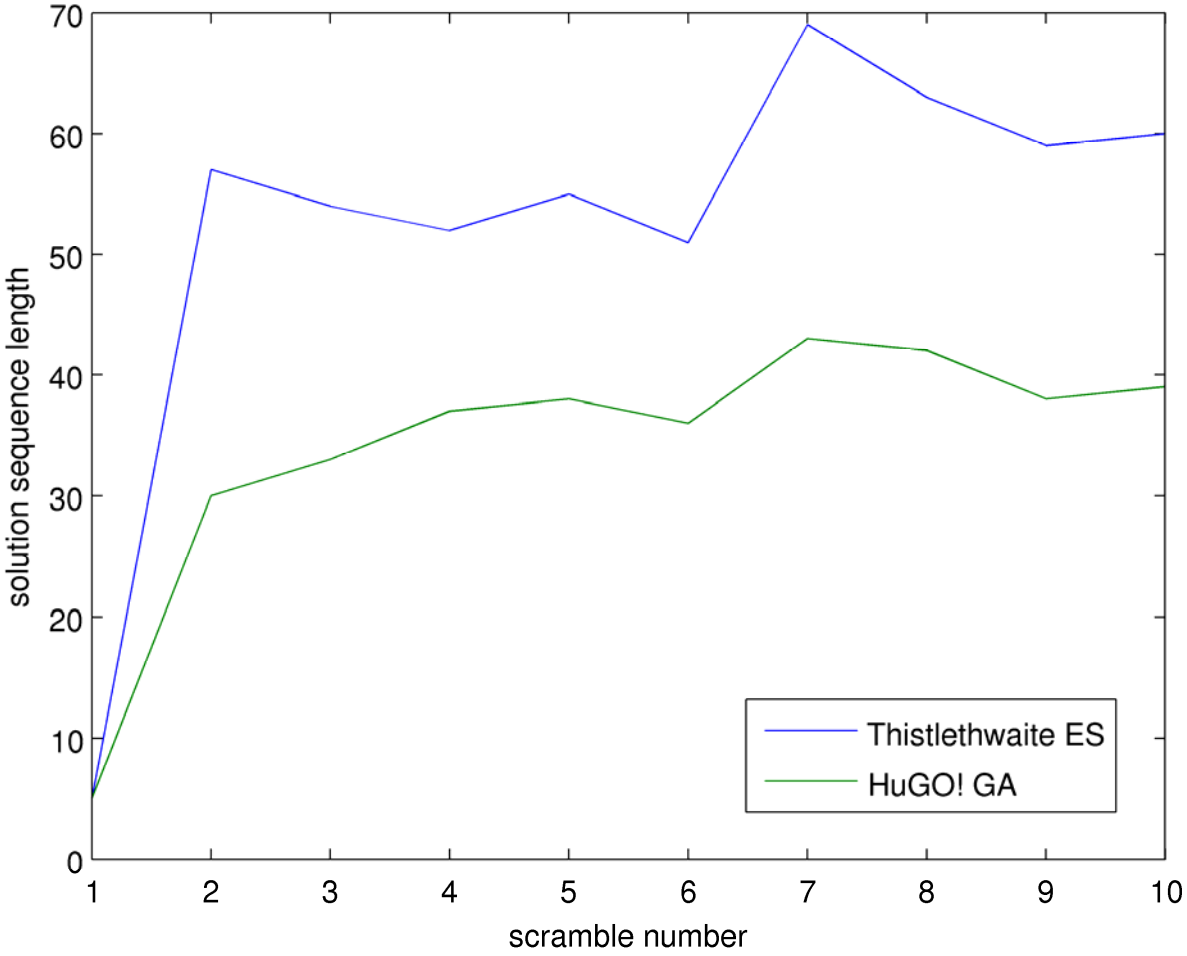
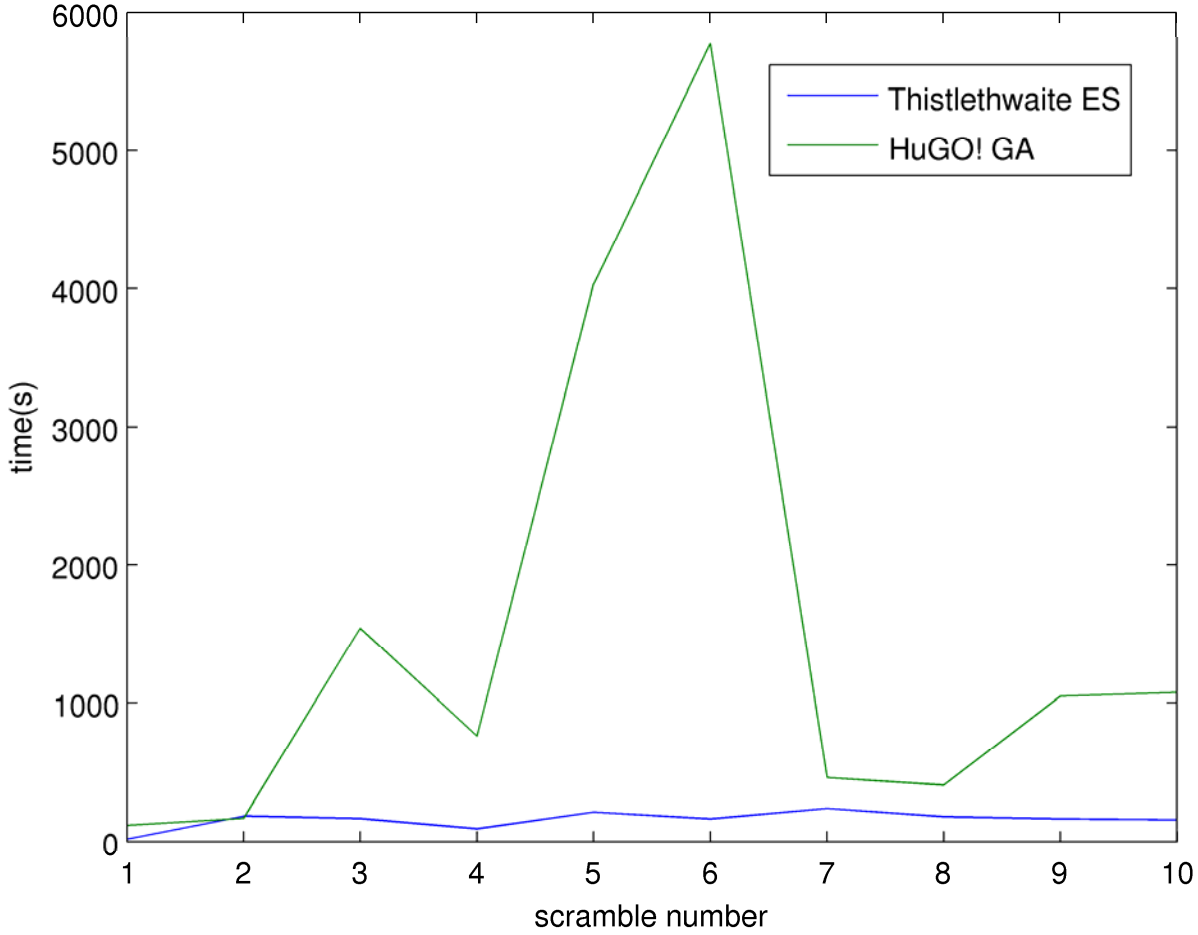
HuGO!

Human strategy based Genetic Optimizer

Qualification for Humies: Total Number of Moves



Qualification for Humies: Time Consumption



Some benchmark results:

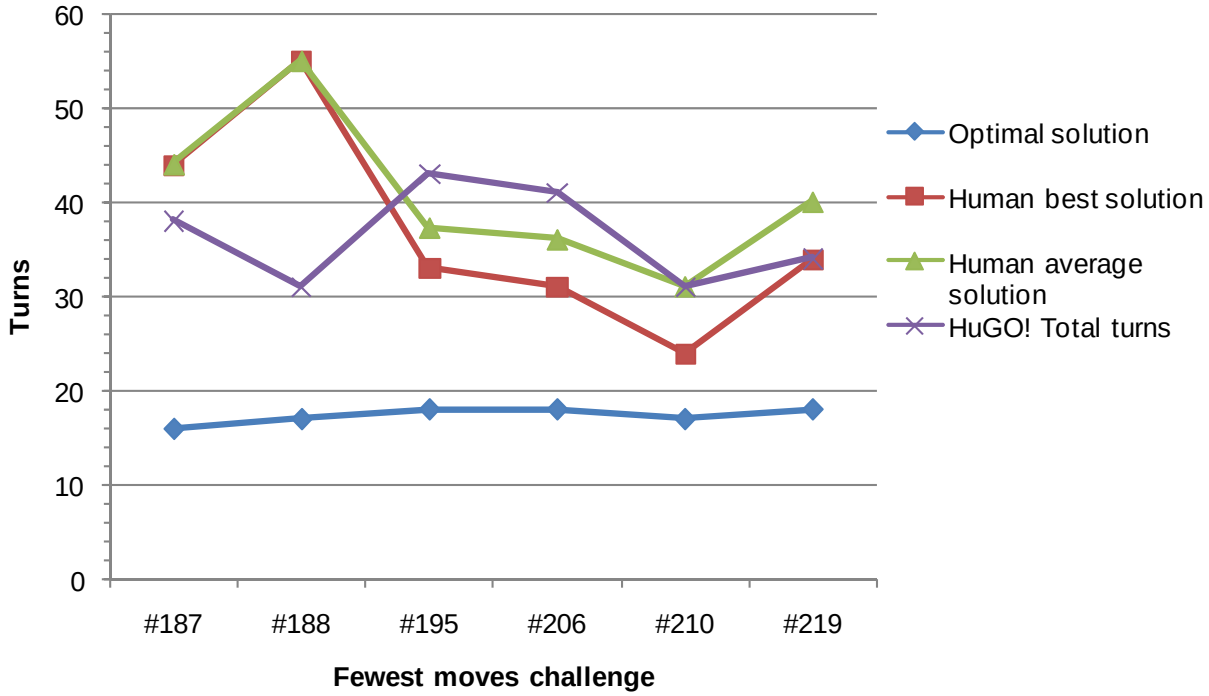
	run 1	run 2	run 3	run 4	run 5
avg. Generations	95.72	100.63	92.71	99.66	92.22
avg. Moves	50.67	50.32	50.87	50.23	49.46
avg. Time(s)	321.78	381.68	393.99	312.98	287.93

solving 100 random scrambles of minimum length 10 and maximum length 50.

- **A**: The result would qualify today as a patentable new invention.
- **B**: The result is better than a result published in a reviewed scientific journal.
- **D**: The result is publishable in its own right as a new scientific result.
- **E**: The result is equal to or better than the most recent human-created solution to a long-standing problem for which there has been a succession of increasingly better human-created solutions.

- **F**: The result is equal to or better than a result that was considered an achievement in its field at the time it was first discovered.
- **G**: The result solves a problem of indisputable difficulty in its field.
- **H**: The result holds its own competition involving human contestants.

HuGO! competes: HuGO!-Human Competition



#187: B F2 D2 L B2 D' L B R2 U' B' F' L B2 L' R B' U2 F B' R D R' D' F' L D' U L'

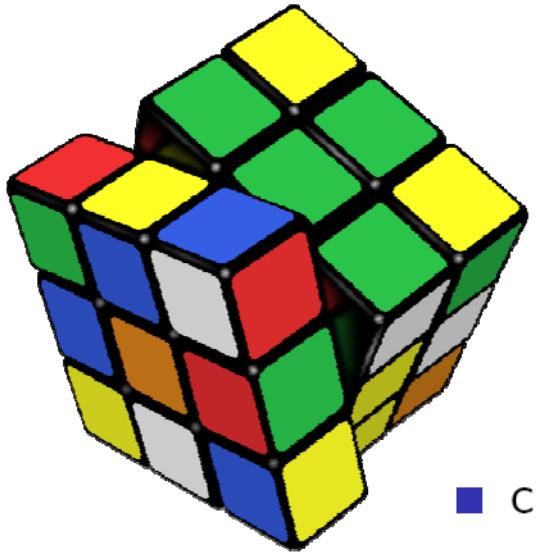
#188: D L' R D' U R F D2 R L' F2 B2 L' U' F2 D U B U B' L2 F U R U2 L' B2 U F' D'

#195: F R' F2 L' D' R' D' R F' L2 R' B2 L2 R' F2 U' D' R' D R F' B2 D B2 F' L2 R2 U' B' D2

#206: D' F2 B' L R' U F U' D2 B R2 L2 D' B2 F R2 L2 D U2 B2 L2 D R D2 U L D R2 U' R'

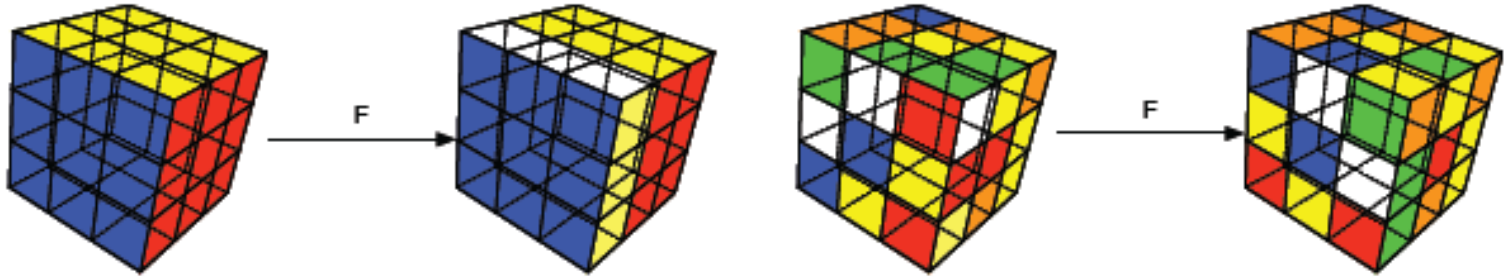
#210: L' F L B' L' B' R' L' D' R L B2 R' D2 F2 R' D2 B R' L D' R2 U B' U' B R L' B2 L'

#219: D' L2 R' F' R B2 R2 F B' R D2 R D B' L' R U2 D L' R2 U D B L' F L2 U D B2 L



- classic 3^3 Rubik's Cube invented in 1974 by Erno Rubik
- highly complex puzzle
- $4.3 \cdot 10^{19}$ unique configurations
- only 1 of these $\rightarrow$ "solved state"
- smallest number of moves to solve ("God's Number") yet unkown
- only few exact approaches exist
- most (promising) based on group theory
- no valid evolutionary approach incorporating group theory until now

- each face is referred to by its position (relative to the users viewpoint)
- common notation is: F, R, U, B, L, D
- these also stand for a 90° clockwise turn



- correspondingly Fi, Ri, Ui, Bi, Li, Di denote counter-clockwise 90° turn

- developed by Morgan Thistlethwaite in 1984
- divides the problem of solving the Cube into 4 subproblems

Definition

$G_0 =< F, R, U, B, L, D > \supset$
$G_1 =< F, U, B, D, R2, L2 > \supset$
$G_2 =< U, D, R2, L2, F2, B2 > \supset$
$G_3 =< F2, R2, U2, B2, L2, D2 > \supset$
$G_4 = I$
with $|G_0| > |G_1| > |G_2| > |G_3| > |G_4|$.

- transition Cube from $G_i \rightarrow G_{i+1}$ only using moves from G_i
- pre-calculated lookup-tables, solves in max. 52 moves

Definition

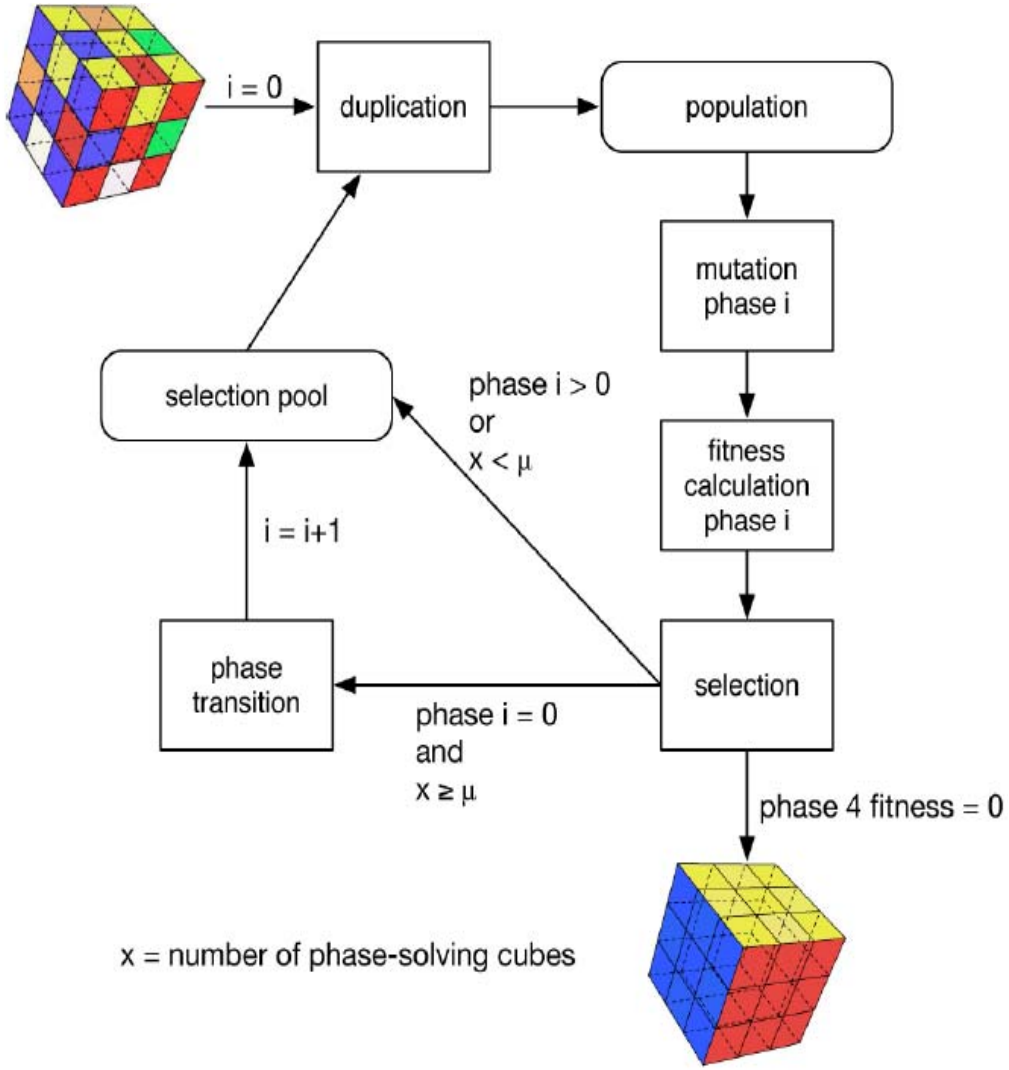
A subset $S \subseteq G$, is called a *generator* of G if any element of G can be written of a product of elements of S and their inverses. This is denoted by $G =< S >$.

thus $G_C =< F, R, U, B, L, D >$ ("Cube Group")
with $|G_C| = 4.3 \cdot 10^{19}$

- $G_0, |G_0| = 4.3 \cdot 10^{19}$
- $G_1, |G_1| = 2.11 \cdot 10^{16}$
- $G_2, |G_2| = 1.95 \cdot 10^{10}$
- $G_3, |G_3| = 6.63 \cdot 10^{5}$

- no constraint
- orientation of edge cubies (2^{11})
- orientation of corner cubies (3^7), transport of edge cubies to/from middle layer$(\frac{12!}{8!\cdot 4!})$
- ...

1. scrambled Cube is duplicated λ times



- each phase has its own fitness function, counting
  1. wrong oriented/positioned cubies according to group constraints
  2. length of remembered sequence list
- weights adjustable

Example $G_0 \rightarrow G_1$:

$$phase0_{fitness} = weight \cdot (w) + c \qquad (1)$$

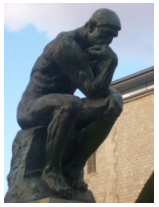
$w :=$ number of wrong oriented edges
$c :=$ length of sequence list

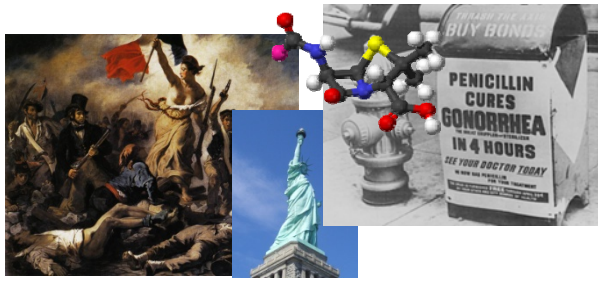
- G_i constraints satisfied if $phase(i)_{fitness} = c$

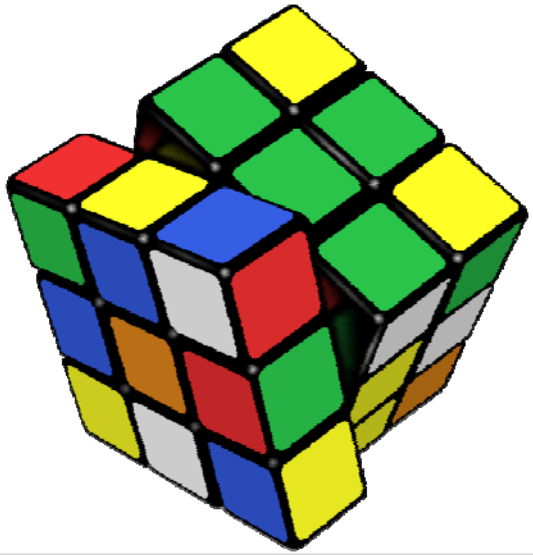
In the work we filed for the award, the **evolution of a human problem-solving strategy** that has been proven successful in many human competitions **and the incorporating of an exact algorithm is considered**, .

- **Therefore**, the approach qualifies for a **new research direction** within Evolutionary Computation, which is determined and inspired by human achievements.
- We understand this to be the major goal of the “HUMIES” AWARDS FOR HUMAN-COMPETITIVE RESULTS.

- This entry does not apply its considerable power to an existential problem, as others might.
- Nor does it present a grand social or medical improvement, which would be highly desirable.
- Although – to be fair – it solves a problem that has irked millions of people since the late 1970s!







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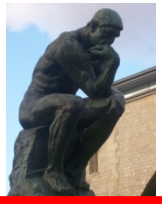
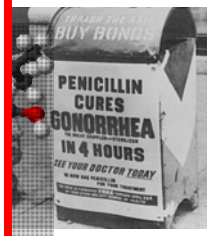
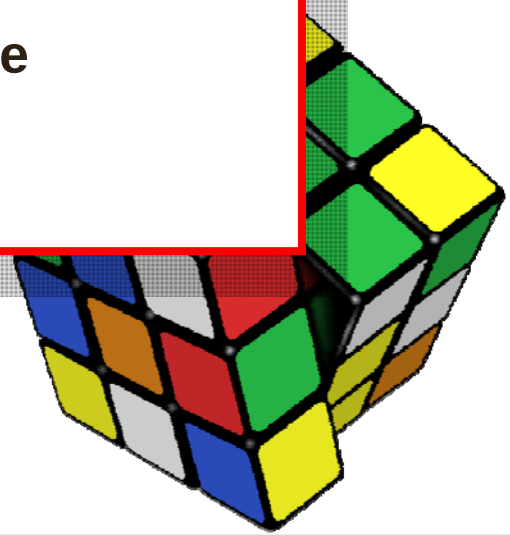


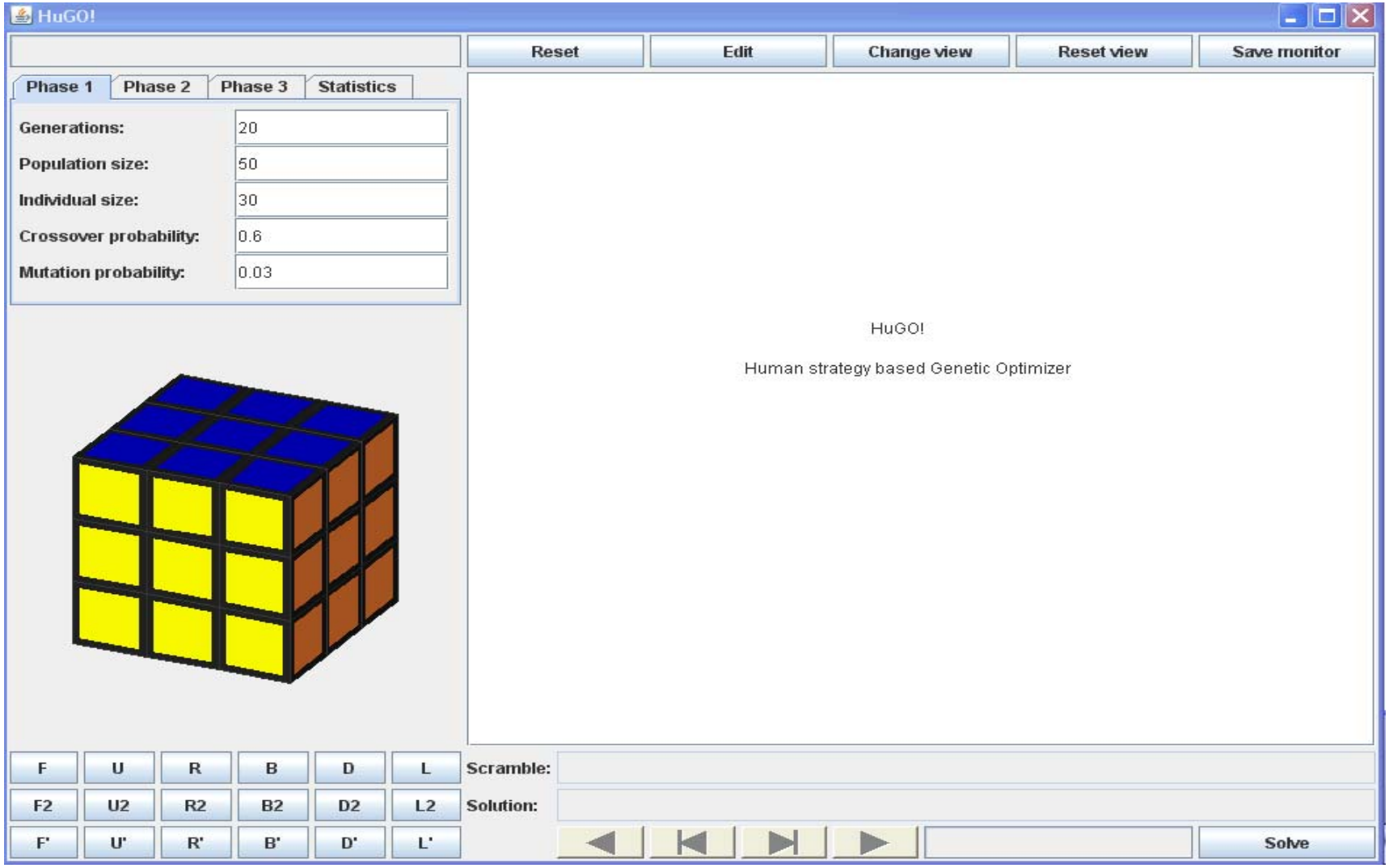
In fact, this entry goes further than that, by

1. supplying a solution on a meta-level and

2. building a background for any of those applications!






HuGO!
Reset
Edit
Change view
Reset view
Save monitor
Phase 1
Phase 2
Phase 3
Statistics
Generations:
20
Population size:
50
Individual size:
30
Crossover probability:
0.6
Mutation probability:
0.03
HuGO!
Human strategy based Genetic Optimizer
F
U
R
B
D
L
F2
U2
R2
B2
D2
L2
F'
U'
R'
B'
D'
L'
Scramble:
Solution:
Solve