

MOHEX WINS HEX TOURNAMENT

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There were four entrants in the 2009 Hex competition: YOPT by Abdallah Saffidine and Tristan Cazenave of France; SIX (version 0.5.3) by Gábor Melis of Hungary; WOLVE by Broderick Arneson, Ryan Hayward, and Philip Henderson of Canada; and MOHEX by Philip Henderson, Broderick Arneson, and Ryan Hayward. The same four programs competed in the 2008 Olympiad. A fifth program, Bit2, registered but withdrew before the competition.

YOPT is a UCT Monte Carlo program that uses the RAVE formula (Gelly and Silver, 2007), some dead cell analysis, and 80K rollouts (with the bridge and 432 patterns) per move. In a pre-competition trial against SIX, YOPT won 99 of 200 games. A non-Olympiad version of YOPT computes virtual connection information in the UCT tree (Cazenave and Saffidine, 2009).

SIX, the 2003-2006 gold medallist and 2008 bronze medallist, uses a 2-ply truncated-width alpha-beta search, a Shannon style electric circuit evaluation function (with cell adjacencies augmented by virtual connections), and some pruning of low degree dead cells.

WOLVE, the 2008 gold medallist and successor to the 2006 and 2003 silver medallist WOLVE and Mongoose programs², is similar to SIX, but with more dead cell analysis and virtual connection computation. Recent improvements include changing the 1-2ply iterative deepening to 1-2-4ply as time permits. On average, one 4ply move takes just over one minute; the variance is large. To save time, WOLVE caches previously computed opening moves.

MOHEX is a UCT Monte Carlo program built on the code base of Fuego, the Go program developed by Martin Müller, Markus Enzenberger, and others at the University of Alberta. Recent improvements include performing virtual connection computation and inferior cell analysis in the UCT tree, and using lock-free parallelization (Enzenberger and Müller, 2009). MOHEX and WOLVE share many features, including an endgame solver which uses one thread and runs in parallel with the rest of the program.

Each player opened once against each opponent. The tournament completed on Tuesday May 12. Gábor Melis did not attend the tournament; SIX's opening moves were picked by Yngvi Björnsson and Jakub Pawlewicz. YOPT, SIX, WOLVE, and MOHEX used 1, 1, 3, and 8 threads respectively.

	MOHEX	WOLVE	SIX	YOPT	total	result
MOHEX		2-0	2-0	2-0	6-0	gold
WOLVE	0-2		1-1	2-0	3-3	silver
SIX	0-2	1-1		1-1	2-4	bronze
YOPT	0-2	0-2	1-1		1-5	4th

Game 1 WOLVE-MOHEX 0-1. MOHEX's evaluation scores suggest this to have been a close game, although post-game analysis shows that MOHEX is winning (in a known winning position) by 34.W[f11].

Game 2 MOHEX-WOLVE 1-0. By 17.W[e4] MOHEX likes its position. Solver finds MOHEX's winning move 41.W[e2], and from that move onwards generates each move for each player. 46.B[b4] looks ineffective, and might be weak against an opponent that has not yet solved the game.

Game 3 WOLVE-SIX 0-1. WOLVE's situation seems to deteriorate after 17.B[d7]. SIX's 24.W[g2] looks brilliant.

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²See previous games competition reports (Melis and Hayward, 2003; Willemson and Björnsson, 2004; Hayward, 2006; Arneson, Hayward, and Henderson, 2008).

SIX is winning by 28.W[e3].

Game 4 SIX-WOLVE 0-1. 17.W[e2] is killed (rendered useless) by 18.B[f2]. Black is winning by 30.B[j6]. 31.W[k1] could be killed by B[j2]; instead, Black plays 32.B[j7]

Game 5 MOHEX-SIX 1-0. MOHEX thinks 14.W[h2] is weak, as its evaluation score (playout win fraction) jumps to 0.75 after 15.B[i5]. MOHEX is winning by 19.B[h5]

Game 6 SIX-MOHEX 0-1. SIX blunders with 39.B[g2], as B[c2] wins. Solver finds the winning reply 40.W[j5] for MoHeX. On the previous move, MOHEX blunders with 38.W[c4], as W[j5] wins.

Game 7 SIX-YOPT 0-1. This game seems very close until near the end. YOPT is winning by 42.B[i5].

Game 8 YOPT-SIX 0-1. This is another close game, this time with SIX pulling ahead. SIX is winning by 48.B[b9]. 56.B[e6] is an elegant move found by SIX's virtual connection engine.

Game 9 YOPT-WOLVE 0-1. Post-match analysis shows WOLVE is winning by 24.W[f8]. WOLVE knows this by 28.W[b7], and so plays seemingly unusual moves from here on. YOPT has no endgame solver and does not see the win; during this endgame its evaluation score climbs over 0.9 before eventually decreasing.

Game 10 WOLVE-YOPT 1-0. During the game, Solver finds the winning 25.B[b10] for WOLVE. The moves up to this point seem human-like. This result ensures gold for MOHEX.

Game 11 YOPT-MOHEX 0-1. The white line of bridges may look strong, but YOPT is winning in moves 27 through 30 before blundering with 31.B[d4]; B[c4] would win here. This result ensures silver for WOLVE.

Game 12 MOHEX-YOPT 1-0. This game seems very close until near the end. A long post-match analysis shows that YOPT reaches a winning position before blundering with 36.B[e2]; B[b3] would win here. MOHEX is winning from 37.W[e1] on. This result ensures bronze for SIX.

Conclusions. The level of play seems stronger than in previous Olympiads, with a higher proportion of very close games. Reflecting the result of this competition, a post-competition tournament of two hundred games between MOHEX and WOLVE shows MOHEX significantly stronger. It is tempting to conjecture that Monte Carlo will become the algorithm of choice for Hex programs.

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1. REFERENCES

Arneson, B., Hayward, R. B., and Henderson, P. (2008). Wolve Wins Hex Tournament. *ICGA*, Vol. 31, No. 4. www.cs.ualberta.ca/~hayward/publications.html.

Cazenave, T. and Saffidine, A. (2009). Utilisation de la recherche arborescente Monte-Carlo au Hex. *Revue d'Intelligence Artificielle*, Vol. 23, Nos. 2–3, pp. 183–202.

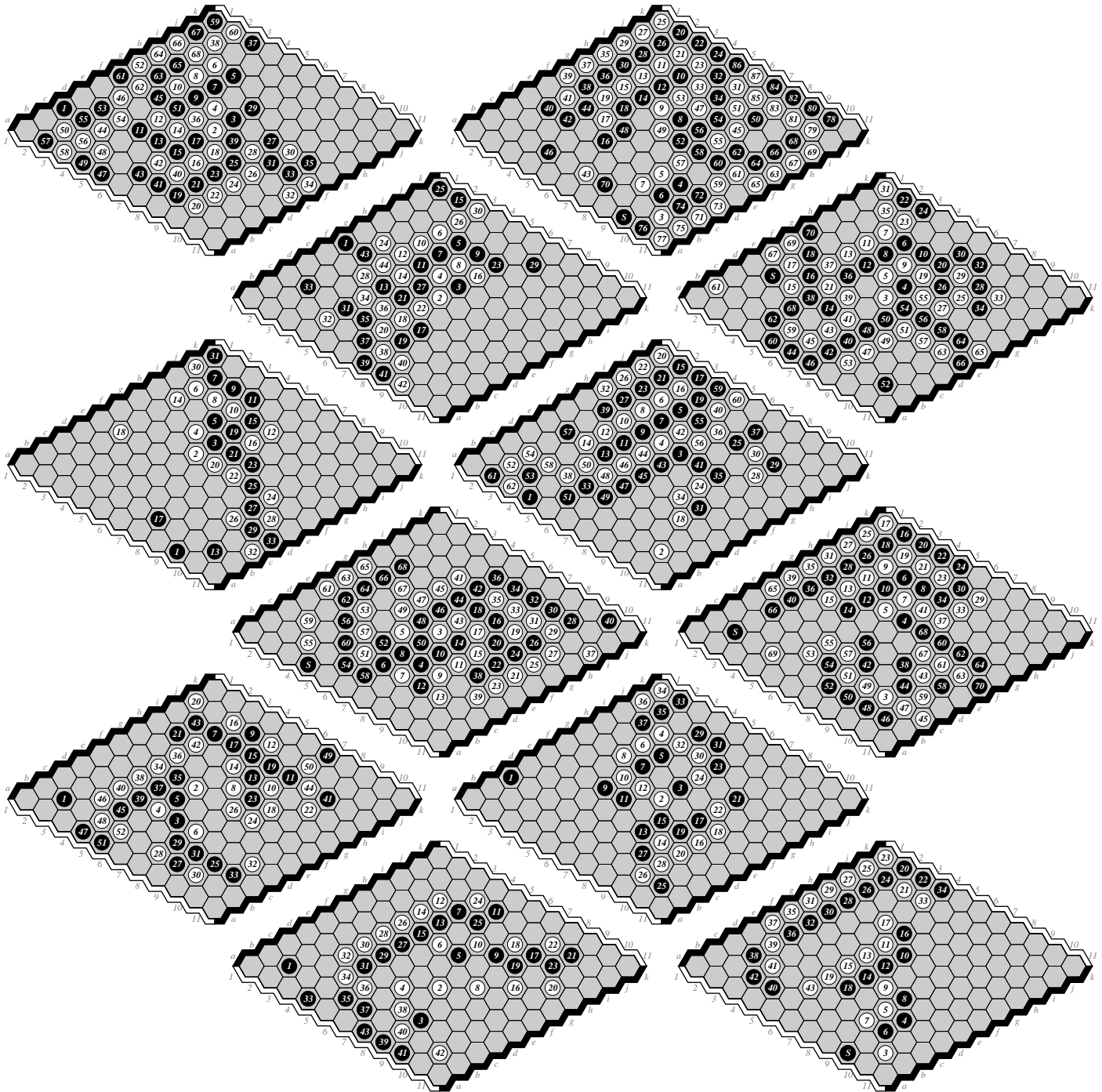
Enzenberger, M. and Müller, M. (2009). A Lock-free Multithreaded Monte-Carlo Tree Search. *Advances in Computer Games 12* (eds. H. J. van den Herik and P. Spronck), Vol. 666 of *Lecture Notes in Computer Science*, pp. 1–12. Springer.

Gelly, S. and Silver, D. (2007). Combining online and offline knowledge in UCT. *ICML '07: Proc. 24th international conference on machine learning*, pp. 273–280.

Hayward, R. B. (2006). Six Wins Hex Tournament. *ICGA*, Vol. 29, No. 3, pp. 163–165.

Melis, G. and Hayward, R. (2003). Six Wins Hex Tournament. *ICGA*, Vol. 26, No. 4, pp. 277–280.

Willemson, J. and Björnsson, Y. (2004). Six Wins Hex Tournament. *ICGA*, Vol. 27, No. 3, p. 180.



Hex tournament. Game 1:WOLVE-MOHEX 0-1, Game 2:MOHEX-WOLVE 1-0 (top row). Game 3:WOLVE-SIX 0-1, Game 4:SIX-WOLVE 0-1 (2nd row). 5:M-S 1-0, 6:S-M 0-1 (3rd row). 7:S-Y 0-1, 8:Y-S 0-1 (4th row). 9:Y-W 0-1, 10:W-Y 1-0 (5th row). 11:Y-M 0-1, 12:M-Y 1-0 (bottom row). In some games the operator of the losing program resigned once the outcome was obvious.