to appear, ICGA Journal

MoHex Wins 2016 Hex 11x11 and 13x13 Tournaments

Ryan Hayward[1], *Noah Weninger* [2], *Kenny Young*[3], *Kei Takada* [4] *and Tianli Zhang* [5]

Edmonton, Canada

In the longer version of the report, we include all games.

Figure 1: Participants and observers at the Hex competitions.

1. THE TOURNAMENTS

There were two Hex tournaments at the 2016 Olympiad: board size 11×11 and board size 13×13. Three programs competed in each tournament: Ezo by Kei Takada, supervised by Masahito Yamamoto, from Japan; HexamaZe by Tianli Zhang from China; and MoHex 2.0 (Huang *et al.*, 2013), by Broderick Arneson, Ryan Hayward, Philip Henderson, Aja Huang, Jakub Pawlewicz, Noah Weninger, and Kenny Young from Canada.

MoHex, the winner of the previous six Olympiad Hex competitions (Hayward *et al.*, 2013), is an MCTS program that uses the Benzene Hex framework built on the code base of Fuego (Enzenberger *et al.*, 2007–2012). MoHex performs knowledge computation in UCT tree nodes visited at least 256 times. MoHex ran on Firecreek, a 24 core shared-memory machine, with 4 cores reserved for the DFPNS solver (Pawlewicz and Hayward, 2013), which produces perfect play if it solves the position within the time allotted. MoHex uses a book — built by Broderick Arneson with Thomas Lincke's method (Lincke, 2000). Noah Weninger expanded the book and added a feature allowing the use of rotational symmetry for openings whose rotation is in the book. For each board size, the book covers at least eight openings.

Ezo is a stronger version of the program that competed in the 2015 Olympiad. Ezo, now based on the Benzene framework, uses iterative deepening depth-first search with an evaluation function using a linear combination of two network connectivity measures (Takada *et al.*, 2015). Ezo ran on two threads of an i7 4790 laptop, with one thread for search and one thread for Benzene's Depth-First Proof Number Search endgame solver.

HexamaZe is a new MCTS program written by Tianli Zhang from Beijing Institute of Technology.

Each tournament was a three-player double round robin, so 12 games in total with 8 games per player.

11×11 Tournament.[6] The tournment took place on June 26 and 27. The final two scheduled games were not played, as by then the outcome had been decided. After the tournament, MoHex and Ezo played two exhibition

[1]Department of Computing Science, University of Alberta, Canada. Email:hayward@ualberta.ca
[2]CS, UAlberta, Email:nweninge@ualberta.ca
[3]CS, UAlberta. Email:kjyoung@ualberta.ca
[4]takada@complex.ist.hokudai.ac.jp
[5]zhtl1995@gmail.com
[6]Source files for this report, including .sgf files, at `https://github.com/ryanbhayward/icga-olympiad-hex`.

same-resource games, with one thread for the search and one thread for the solver. They each won one game. In the tournament, the operator usually resigned once the Benzene solver detected a win or loss.

11x11 results	MoHex	Ezo	Hexamaze	total	result
MoHex		4-0	3-0	7-0	gold
Ezo	0-4		3-0	3-4	silver
Hexamaze	0-3	0-3		0-6	bronze

This is the longer version, so we include all games.

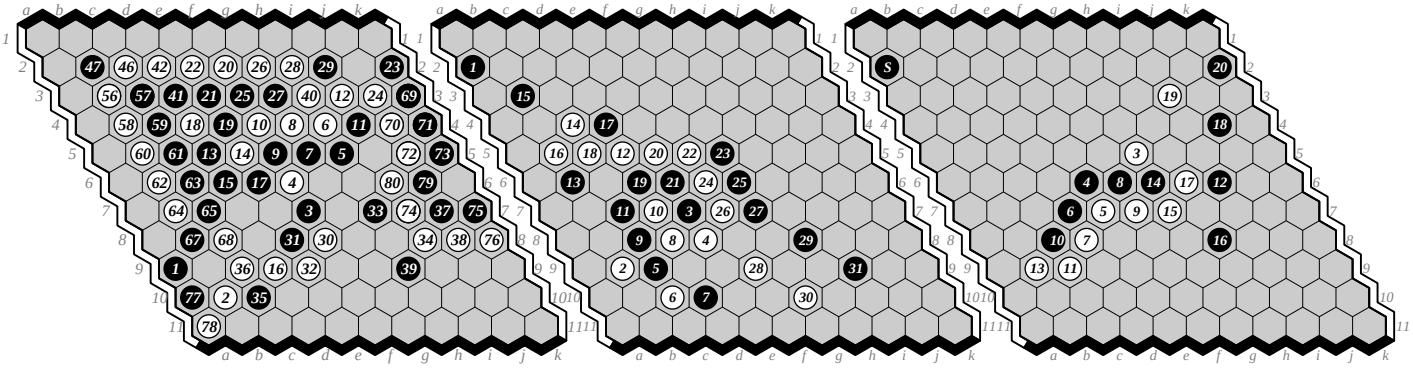

Figure 2: Game 1: Ezo-MoHex 0-1. Game 2: MoHex-Hexamaze 1-0. Game 3: Hexamaze-Ezo 0-1.

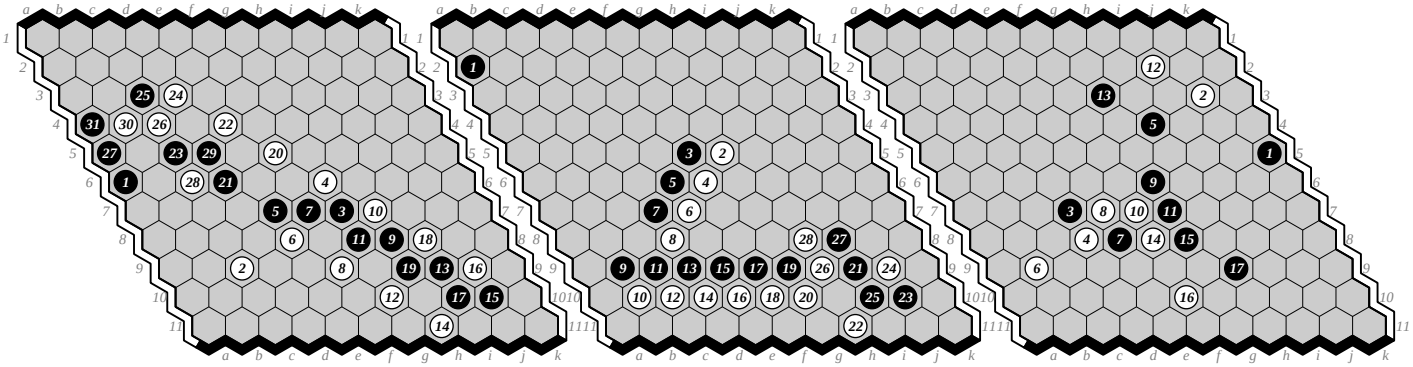

Figure 3: Game 4: MoHex-Ezo 1-0. Game 5: Hexamaze-MoHex 0-1. Game 6: Ezo-Hexamaze 1-0.

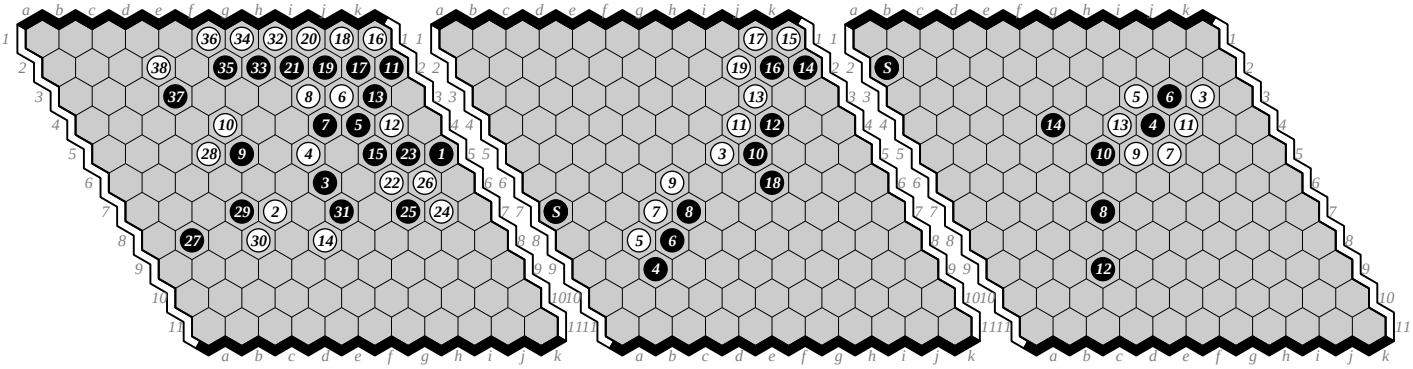

Figure 4: Game 7: Ezo-MoHex 0-1. Game 8: MoHex-Hexamaze 1-0. Game 9: Hexamaze-Ezo 0-1.

13×13 Tournament. The tournament took place on June 30 and July 1. As with 11×11, there was clear separation between each pair of players. In games 10 and 12 MoHex played first in the centre, allowing the opponent to swap and take what is presumably the strongest possible opening move.

13x13 results	MoHex	Ezo	Hexamaze	total	result
MoHexNet		4-0	4-0	8-0	gold
Ezo	0-4		4-0	4-4	silver
Hexamaze	0-4	0-4		0-8	bronze

2. CONCLUSIONS

In pre-tournament tests, Ezo won 65% of its games against 1-thread MoHex, but here the 20-thread search of MoHex was too strong. Hexamaze played well when allowed the centre against MoHex, forcing a long game.

The next step is to add neural nets. For this tournament, the MoHex team prepared MoHexNet, a program that combines the MCTS tree and a depth-1 tree found by NeuroHex, a Deep Convolution Neural Net (Young, Vasan, and Hayward, 2016). On typical swap-game openings, MoHexNet wins 55% of its games against MoHex, a small first step towards an AlphaGo-style player.

Acknowledgements. We thank the NSERC Discovery Grant Program for research funding and Martin Müller for the loan of his machine Firecreek.

3. REFERENCES

Enzenberger, M., Müller, M., Arneson, B., Segal, R., Xie, F., and Huang, A. (2007–2012). Fuego. `http://fuego.sourceforge.net/`.

Hayward, R. B., Arneson, B., Huang, S.-C., and Pawlewicz, J. (2013). MoHex Wins Hex Tournament. *ICGA*, Vol. 36, No. 3, pp. 180–183.

Herik, H. J. van den, Iida, H., and Plaat, A. (eds.) (2014). *Computers and Games - 8th International Conference, CG 2013, Yokohama, Japan, August 13-15, 2013, Revised Selected Papers*, Vol. 8427 of *Lecture Notes in Computer Science*. Springer.

Huang, S., Arneson, B., Hayward, R. B., Müller, M., and Pawlewicz, J. (2013). MoHex 2.0: A Pattern-Based MCTS Hex Player. In van den Herik et al. (van den Herik, Iida, and Plaat, 2014), pp. 60–71.

Lincke, T. R. (2000). Strategies for the Automatic Construction of Opening Books. *Computers and Games* (eds. T. A. Marsland and I. Frank), Vol. 2063 of *Lecture Notes in Computer Science*, pp. 74–86, Springer. ISBN 3–540–43080–6.

Pawlewicz, J. and Hayward, R. B. (2013). Scalable Parallel DFPN Search. In van den Herik et al. (van den Herik *et al.*, 2014), pp. 138–150.

Takada, K., Honjo, M., Iizuka, H., and Yamamoto, M. (2015). Developing Computer Hex Using Global and Local Evaluation Based on Board Network Characteristics. *Advances in Computer Games - 14th International*

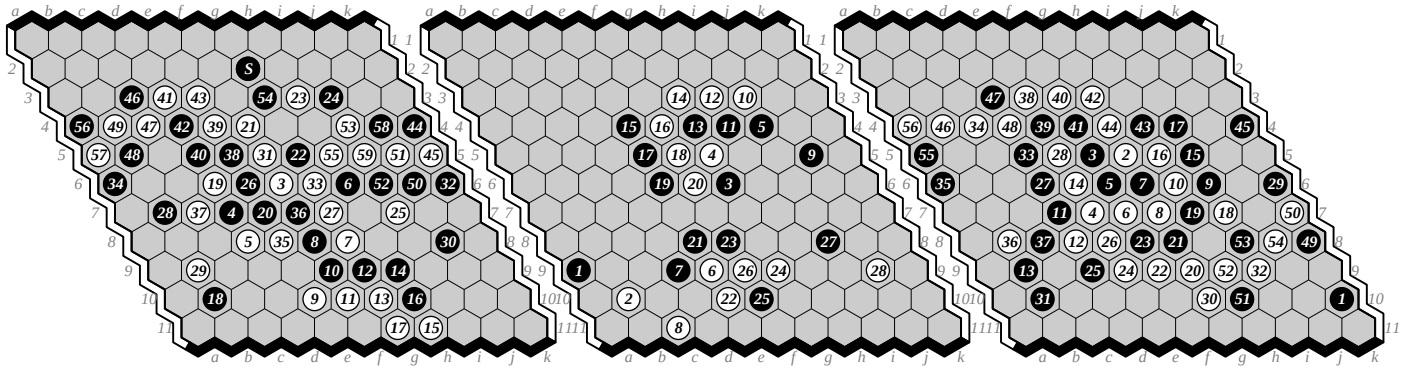

Figure 5: Game 10: MoHex-Ezo 1-0. Exhibition 1-thread games: Ezo-MoHex 0-1, MoHex-Ezo 0-1.

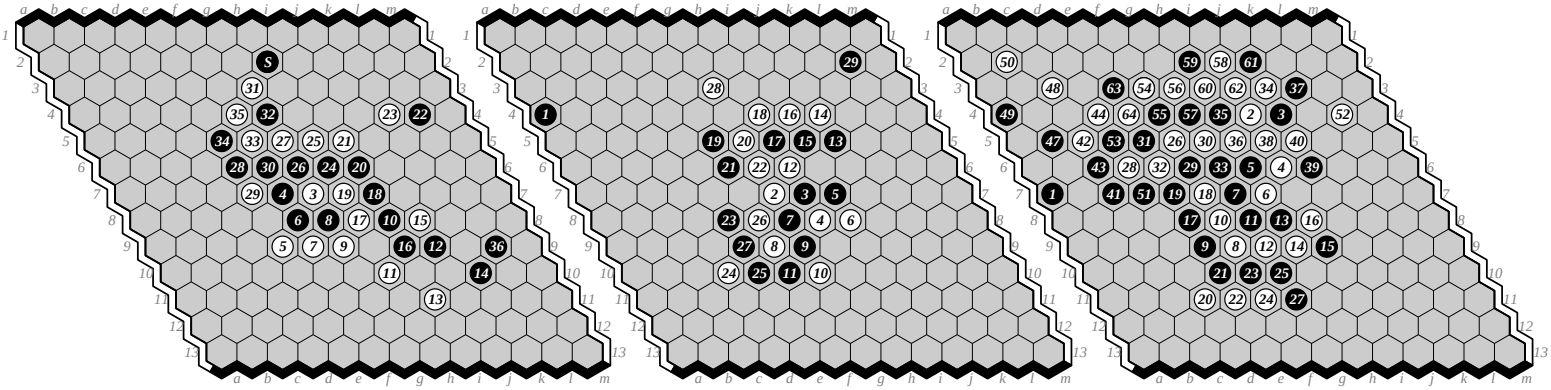

Figure 6: Game 1: EZO-MOHEX 0-1. Game 2: MOHEX-HEXAMAZE 1-0. Game 3: HEXAMAZE-EZO 0-1.

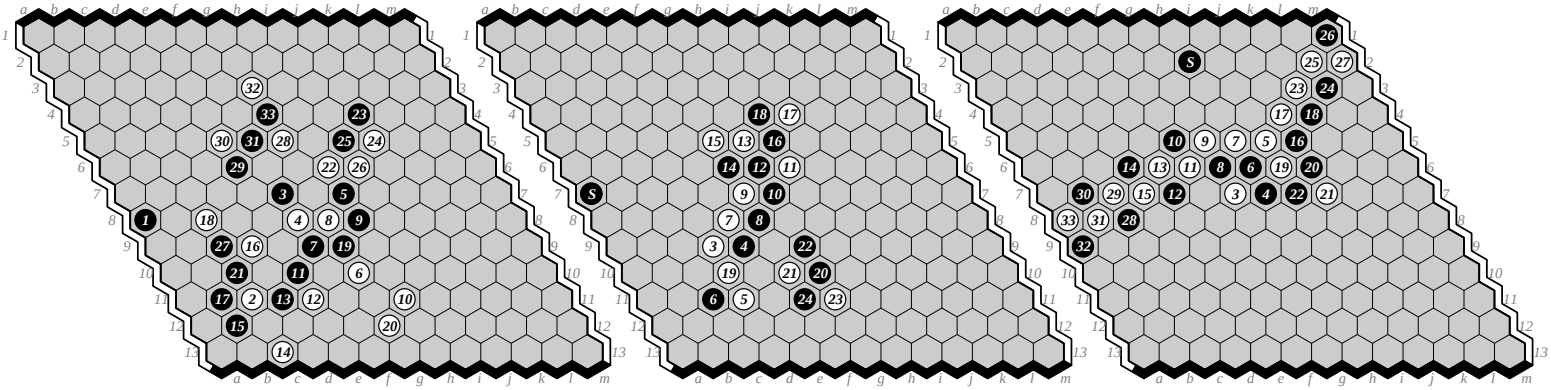

Figure 7: Game 4: MOHEX-EZO 1-0. Game 5: HEXAMAZE-MOHEX 0-1. Game 6: EZO-HEXAMAZE 1-0.

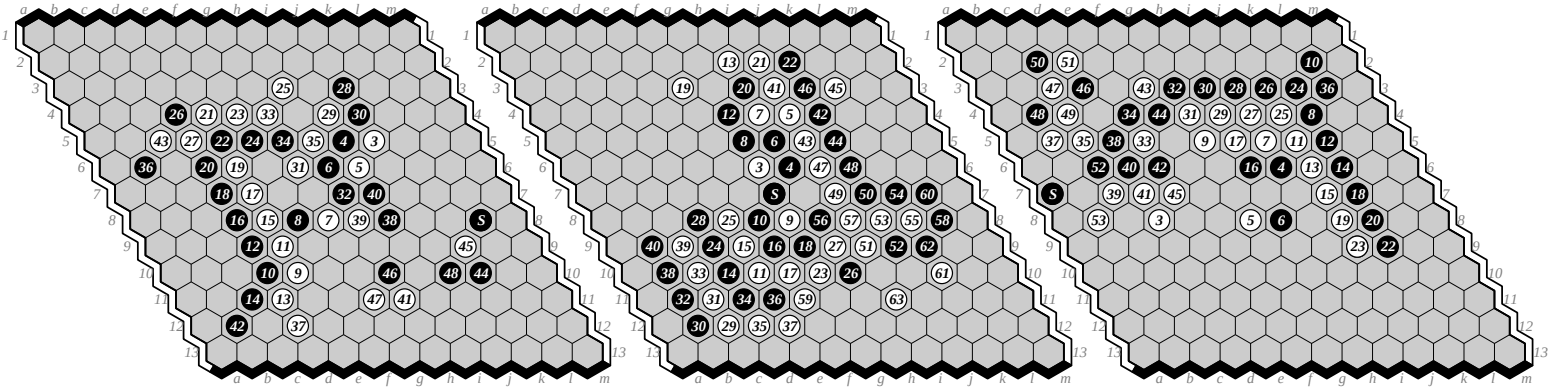

Figure 8: Game 7: EZO-MOHEX 0-1. Game 8: MOHEX-HEXAMAZE 1-0. Game 9: HEXAMAZE-EZO 0-1.

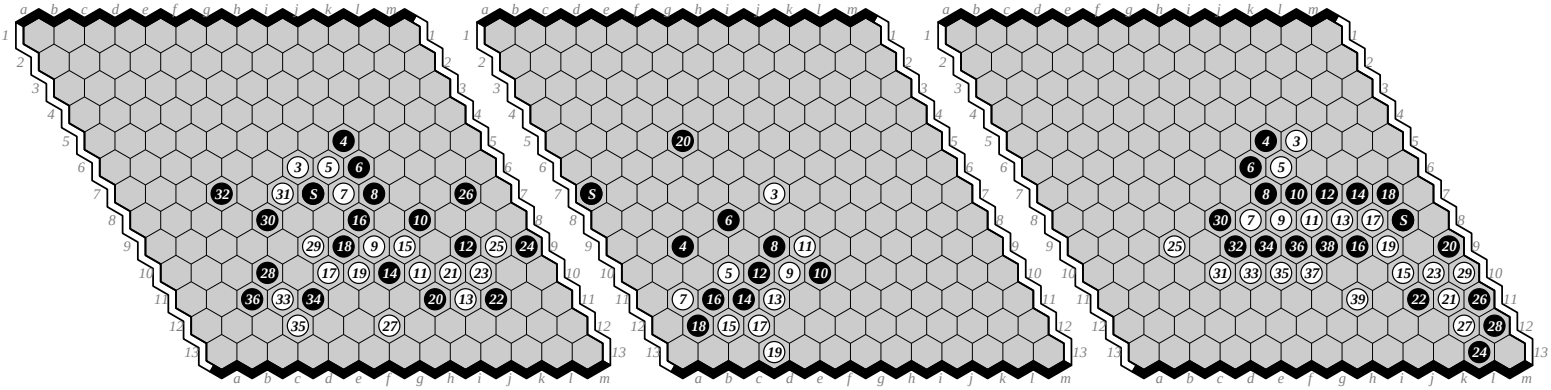

Figure 9: Game 10: MOHEX-EZO 1-0. Game 11: HEXAMAZE-MOHEX 0-1. Game 12: EZO-HEXAMAZE 1-0.

Conference, ACG 2015, Leiden, The Netherlands, July 1-3, 2015, Revised Selected Papers (eds. A. Plaat, H. J. van den Herik, and W. A. Kosters), Vol. 9525 of *Lecture Notes in Computer Science*, pp. 235–246, Springer.

Young, K., Vasan, G., and Hayward, R. B. (2016). NeuroHex: A Deep Q-Learning Hex Agent. *Proc. Computer Games Workshop, IJCAI.*