Guest Editorial Special Issue on Deep/Reinforcement Learning and Games

DEEP learning (DL) and reinforcement learning (RL) have been applied with great success to many games, including *Go* and *Atari 2600* games. Monte Carlo Tree Search (MCTS), developed in 2006, can be viewed as a kind of online RL. This technique has greatly improved the level of *Go*-playing programs. MCTS has since become the state of the art for many other games including *Hex*, *Havannah*, and general game playing, and has found much success in applications as diverse as scheduling, unit commitment problems, and probabilistic planning.

DL has transformed fields such as image and video recognition and speech understanding. In computer games, DL started making its mark in 2014, when teams from the University of Edinburgh and Google DeepMind independently applied deep convolutional neural networks (DCNNs) to the problem of expert move prediction in *Go*. Clark and Storkey's DCNN achieved a move prediction rate of 44%, exceeding all previously published results. DeepMind's publication followed soon after, with a DCNN that reached 55%.

The combination of DL and RL led to great advances in *Atari 2600* game playing, and to the ultimate breakthrough in computer *Go*. In 2017, DeepMind proposed a new deep reinforcement learning (DRL) algorithm and developed AlphaGo Zero, which is significant for not requiring any human knowledge of *Go*. By removing the requirement for domain knowledge, DRL is also flexible in that the method can be applied to a wide range of games and problems, ushering in a variety of new research opportunities.

In this special issue, we are delighted to bring you eight articles on applying DL/RL related techniques to games research. The papers can be grouped into three categories. The first is the application of DL/RL in developing a game AI program. This includes "Move Prediction Using Deep Convolutional Neural Networks in *Hex*," "Can Deep Networks Learn to Play by the Rules? A Case Study on *Nine Men's Morris*," "Learning to Play *Othello* With Deep Neural Networks," "Automatic Bridge Bidding Using Deep Reinforcement Learning," and "Multilabeled Value Networks for Computer Go."

1) "Move Prediction Using Deep Convolutional Neural Networks in *Hex*," by Gao *et al.:* In this article, the authors train a neural net model to predict moves by deep learning using self-play games of the MoHex 2.0 program. Moreover, it combines the model with MCTS to further improve the strength, which surpasses MoHex 2.0.
2) "Can Deep Networks Learn to Play by the Rules? A Case Study on *Nine Men's Morris*" by Chesani *et al.:* In this article, the authors try to assess whether deep learning networks can learn the rules of a game without any prior knowledge, simply through observing matches. The result from the case study of *Nine Men's Morris* shows that it is capable of correctly discriminating legal from illegal moves.
3) "Learning to Play *Othello* With Deep Neural Networks" by Liskowski *et al.:* In this article, the authors train a neural network through several CNN architectures. The best CNN model not only surpasses all other 1-ply *Othello* players proposed to date but defeats the best open-source *Othello* player.
4) "Automatic Bridge Bidding Using Deep Reinforcement Learning" by Yeh *et al.*: In this article, the authors propose a flexible and pioneering bridge-bidding system, based on a novel deep reinforcement learning model. The model includes an upper-confidence-bound algorithm to achieve a balance between exploration and exploitation. The result demonstrates a promising performance of the proposed model, especially achieving a superior performance compared with a champion-winning computer bridge program.
5) "Multilabeled Value Networks for Computer Go" by Wu *et al.*: In this article, the authors train a value network for *Go* with multiple game results according to different game settings (komi). The result shows that training with multiple labels yields better performance compared with training with a single label. The model is also able to play handicap games and support dynamic komi.

The two papers in the next group focus on the enhancement of deep reinforcement learning. They are "Exploration in Continuous Control Tasks via Continually Parameterized Skills" and "Learning to Navigate Through Complex Dynamic Environment with Modular Deep Reinforcement Learning."

6) "Exploration in Continuous Control Tasks via Continually Parameterized Skills" by Dann *et al.:* This article proposes a reinforcement learning method, which applies abstract action sets with hierarchically composed parameterized skills instead of actions. The method can improve the efficiency of exploration and its long-term performance in control tasks such as video games.

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7) "Learning to Navigate Through Complex Dynamic Environment with Modular Deep Reinforcement Learning" by Wang *et al.:* This article divides the main navigation task into two subtasks, local obstacle avoidance and global navigation, and trains the two networks separately. This can not only obtain a better performance with a higher success rate but also enable parallel training.

Finally, "Compressing Chinese Dark Chess Endgame Databases by Deep Learning" investigates other techniques of deep learning which are applicable for AI design.

8) "Compressing Chinese Dark Chess Endgame Databases by Deep Learning" by Chen *et al.:* This article proposes an approach to improve the efficiency of the encoding scheme for the compression of end-game databases, which is time infeasible using the traditional compression technique, by deep learning. The result can be applied to other chess-like games.

We believe that these articles are great contributions that will inspire readers to come up with more innovative and significant ideas in computer games.

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He is currently with the Department of Computer Science, National Chiao Tung University, Hsinchu, Taiwan. He introduced the new game, *Connect6*, a kind of six-in-a-row game. Since then, *Connect6* has become a tournament item in Computer Olympiad. He wrote more than 100 papers, and served as Chair and a committee member in more than 30 academic conferences and organizations, including the conference chair of 2015 IEEE CIG. His research interests include computer games, deep learning, and reinforcement learning.

Dr. Wu is on the editorial board of the IEEE Transactions on Games and the *ICGA Journal*. He is the Vice President of the International Computer Games Association, and was the President of the Taiwanese Association for Artificial Intelligence from 2015 to 2016. He led a team developing various game playing programs, winning more than 50 gold medals in international tournaments, including Computer Olympiad.

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Dr. Lee was the recipient of the Certificate of Appreciation for outstanding contributions to the development of IEEE Standard 1855TM-2016 (IEEE Standard for Fuzzy Markup Language). He is an IEEE CIS Summer Schools Subcommittee Chair in 2018. He was IEEE CIS Tainan Chapter Chair (August 2015–July 2017), IEEE CIS Emergent Technologies Technical Committee (ETTC) Chair from 2009 to 2010, and ETTC Vice-Chair in 2008. He is also an Associate Editor or an Editor Board Member of international journals, such as the IEEE Transactions on Games, *Applied Intelligence*, *Soft Computing*, *Journal of Ambient Intelligence and Humanized Computing*, *International Journal of Fuzzy Systems* (IJFS), *Journal of Information Science and Engineering*, and *Journal of Advanced Computational Intelligence and Intelligent Informatics*. He also guest edited special issues in the IEEE Transactions on Compjutational Intelligence and AI in Games, *Applied Intelligence*, *Journal of Internet Technology*, and *Iranian Journal of Fuzzy Systems*. He was the General Co-Chair of IEEE CIG 2015, the General Chair of TAAI 2015, the Program Chair of FUZZ-IEEE 2011, the Competition Chair of FUZZ-IEEE 2013, and the Competition Co-Chair of FUZZ-IEEE 2015, FUZZ-IEEE 2017, IEEE WCCI 2016, and IEEE WCCI 2018.

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Dr. Tian was the recipient of 2013 ICCV Marr Prize Honorable Mentions.

Martin Müller received the B.A. (equiv.) degree in economic geography from the Ludwig-Maximilians-Universität München, in 2008, the M.Phil. degree in development studies from the University of Cambridge in 2005, and the Ph.D. degree in human geography from the Goethe-Universität Frankfurt am Main, in 2008. He is a Professor with the Department of Computing Science, University of Alberta, Edmonton, AB, Canada. He is interested in all aspects of modern heuristic search, studying the complex interactions between search, knowledge, simulations, and learning. His application areas include game tree search, domain-independent planning, and combinatorial games. He has worked on Computer Go for 30 years, and is the Leader of the open source project Fuego. In 2009, Fuego became the first program to win a 9×9 Go game on even terms against a top-ranked professional player. With his students and colleagues, he has developed a series of successful planning systems based on macrolearning and on Monte Carlo random walks. His paper with C. Xiao and J. Mei titled "Memory-Augmented Monte Carlo Tree Search" was the recipient of the Outstanding Paper Award at AAAI'18.

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