

Supervisor’s Review on the Doctoral Thesis

Author: Mgr. Martin Schmid
Title: Search in Imperfect Information Games

Let me begin with a personal note. When Martin was about to enroll the doctoral studies, he told me seriously that during the studies he is likely to publish a paper in Science. Of course, I considered his statement to be exaggerated, but as time went by, it turned out that Martin was right...

Contents of the thesis

The thesis is devoted to solving games and naturally it is divided into two parts – the perfect and imperfect information games. The former gives an overview on perfect information games by introducing the basic definitions, concepts, offline and online solving and search in the game three. The main part of the thesis are imperfect information games and the particular focus is on search in the tree and solving the games. The text comprises the classical approaches as well as the top methods known. In particular, there are described the offline solving techniques of reinforcement learning, regret minimization (including counterfactual regret minimization and its variants) and abstractions; online solving techniques with the concepts of soundness and search consistency; and many techniques for effective search in the game tree. The thesis concludes with a chapter on DeepStack, which was the first program that beat professional human players in no-limit Texas hold’em poker and which was developed by Martin Schmid and Matej Moravčík (as the main authors).

The thesis can serve as a book providing an introduction to the topic as well as showing state-of-the-art concepts and methods. It contains many illustrative examples and pictures. On the other hand, notation and presentation could be slightly improved as it can sometimes be little bit confusing. For instance,

- symbol Δ has two different meanings on pages 19–20
- page 37: information state/set is unused before it is introduced
- Figure 7.2: How Ω can be exploitable, when it is a Nash equilibrium?
- “mbb” could be introduced
- page 163; The list of acronyms would be more useful if more acronyms are involved (e.g., MDP, BRV, EFG, FOSG, POMDP, ...)

Scientific contribution

The thesis involves scientific results and contribution of Martin’s work. In particular, the highest achievements are the following:

- Based on linear programming reformulation, the support size of optimal strategies can be a priori bounded.
- Sub-game refinement. A new way for refinement of sub-games for abstraction-based methods is proposed. Among its appealing properties, it can be proved that it is no more exploitable than the original sub-game (utilizing the concept of sub-game margin).
- The proposed Variance reduced MCCRm (Monte Carlo counterfactual regret minimization method). It is a new variant of MCCRm that can decrease the sample variance and, as a consequence, accelerates the convergence in orders of magnitude.
- Formalization of soundness and search consistency for online setting. This allows for analysis of worst case behaviour of search algorithms.
- AIVAT. This technique considerably reduced the variance in evaluation of poker matches so that less games are needed to play to obtain statistically significant results.
- DeepStack. It was the first program that beat professional human players in no-limit Texas hold'em poker, and it was the basis for the paper in Science. This groundbreaking result is comparable with beating humans in the games of chess or Go. The main authors of DeepStack were Martin Schmid and Matej Moravčík.

Summary

Martin's scientific results are amazing. He published in prestigious journals and proceedings (including Science and top ranked AAAI Conference on Artificial Intelligence). The achievement of the poker program DeepStack is really groundbreaking.

Therefore I recommend to **accept** the thesis. Moreover, I believe it can be nominated for a best PhD thesis prize.

In Prague, July 8, 2021

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