FACULTY OF ELECTRICAL ENGINEERING CTU IN PRAGUE

The referee's report on the thesis *Bridging the Gap: Towards Unified Approach to Perfect and Imperfect Information Games* by *Matej Moravčík*

Summary of results

This thesis presents a comprehensive study of advanced AI techniques in imperfect information games, showcasing significant strides in AI capabilities. The main achievements are *DeepStack* (general-purpose algorithm for a large class of sequential imperfect information games) and *Player of Games* (a universal algorithm to play both perfect and imperfect information games, combining the ideas from *DeepStack* and *AlphaZero*).

In particular, Martin Moravčík's contribution in those two areas was in both *theoretical advancements* (corrected proofs for the solution error in CFR+, bounds on the support size in extensive-form games with imperfect information, and the analysis of algorithms for online search) and the *design of novel algorithms* (variance reduction techniques in MCCFR, online improvement of strategies based on safe refinement of subgames, and significant contributions to *DeepStack* and *Player of Games*).

Evaluation of novelty and impact

DeepStack was one of the first AI systems to demonstrate a professional-level skill in heads-up no-limit Texas hold'em poker, a milestone in AI research. Its ability to handle complex, imperfect-information environments suggests potential applications far beyond poker. *Player of Games* is the first universal algorithm achieving strong performance in domains with both perfect and imperfect information and minimal domain-specific knowledge.

The immediate impact of Matej Moravčík's results is also witnessed by the publications in top-notch journals (Science, Journal of Artificial Intelligence Research) and best AI conferences (1x AAMAS, 4x AAAI).

Questions for the defense

1. In the thesis only *two-player zero-sum extensive-form games with perfect recall* are considered. Would it be possible to generalize and extend your solution and learning techniques also to more general classes of games, such as a) *n*-player zero-sum polymatrix games (Cai, Y., et al. Zero-sum polymatrix games: A generalization of minmax. *Math. Oper. Res.* 41, 648–655 (2016)), b) two-player patrolling security games (Basilico, N. et al. Patrolling security games: Definition and algorithms for solving large instances with single patroller and single intruder. *Artif. Intell.* 184-185, 78–123 (2012)), or c) other classes of games discussed in the area of multiagent reinforcement learning?

2. Can you please briefly comment on the differences and similarities between your arxiv paper Schmid, M. et al.. Player of Games. arXiv preprint arXiv:2112.03178 (2021) cited in the thesis and the paper

   Schmid, Martin, et al. "Student of Games: A unified learning algorithm for both perfect and imperfect information games." *Science Advances* 9.46 (2023)

3. Can you explain why LP2 on p.70 is not formulated as a linear feasibility problem directly?

4. The section 11.2 Future Work is rather sketchy and brief. Can you elaborate on some of the future research streams?

Recommendation for PhD degree granting

Given the top quality of the research, important contributions to the field of algorithmic game theory, and the candidate's in-depth understanding demonstrated in the written thesis,

I recommend awarding the Ph.D. degree to Matej Moravčík.

The dissertation not only meets but exceeds the standards of doctoral-level scholarship and represents a meaningful advancement in the theory of extensive-form games with imperfect information.

14 January 2024 Doc. Ing. Tomáš Kroupa, Ph.D.