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Review Report on Doctoral Thesis

PhD candidate: **Mgr inż. Konrad Godlewski**
Thesis title: ***"Monte Carlo Tree Search and Reinforcement Learning methods for multi-stage strategic card game"***.
Supervisor: **dr hab. Inż. Bartosz Sawicki**
Institution: **Warsaw University of Technology (Politechnika Warszawska)**
Doctoral Study Programme/Scientific Discipline: **Technical Information Technology and Telecommunications (Informatyka Techniczna i Telekomunikacja)**

The purpose of this review is to determine whether this doctoral dissertation meets the requirements for theses at this stage of education and whether it meets the conditions listed in the following points:

1. **Relevance of the chosen dissertation topic.**
Ad. 1.
In this doctoral dissertation, the author presented the application of machine learning methods to create agents of a card game titled "The Lord of the Rings: The Card Game" (LOTRCG). The choice of the dissertation topics is fully consistent with the discipline in which the doctoral student is going to defend his thesis - which is **Technical Information Technology and Telecommunications**. The content and content of the work are fully consistent with the topic of this work. I have no objections whatsoever to fulfilling this point.

2. **Definition and fulfilment of the dissertation objectives.**
Ad. 2.
The topic of the thesis is "Monte Carlo Tree Search and Reinforcement Learning methods for multi-stage strategic card game". In this work, the author presented the application potential of machine learning methods to create agents for a card game. The nature of the described gameplay presented in this dissertation is complex, sequential, which

means that a decision made in one phase of the game affects its subsequent phases. Random events make it impossible to combine several decision-making moments.

As the proposed game is characterised by a lot of variety, it is also a big challenge for AI agents. To overcome these, the author proposed the use of two different families of computational intelligence techniques. The first of them is the Monte Carlo Tree Search (MCTS) method, which is based on heuristic search using random sampling of game states. The win rate obtained in this way is **82.8%**, which can be considered a high result. The second of the presented and analysed techniques is Reinforcement Learning (RL), which is based on a trial and error method in which the agent is interacting with the environment. The best (in the author's opinion) set of RL agents showed a very high efficiency of **95.3%**.

The author stated that the main aim of his doctoral thesis project was verification whether AI-based methods can successfully play strategic card game (LOTRCG). Experimental results were above **95%**, so such high efficiency allow to draw conclusions about the fulfillments of the assumptions of the doctoral thesis.

3. Evaluation of the obtained results in terms of significant contribution to the scientific field.
Ad. 3.

The results of the conducted work were proven with the high efficiency (win results) of **82.8%** and **95.3%** respectively.

The doctoral student, moreover, has a fairly good (as for this stage of his scientific career) publication achievements. In 2022, he published an article entitled: "Monte Carlo tree search: A review of recent modifications and applications" in the journal Artificial Intelligence Review, for **140** points. This article has already been (according to Google Scholar) cited **32** times. The author is also co-author (leading author) of the publication entitled "Optimization of MCTS player for the Lord of the Rings: The Card Game" published in 2021 in Bulletin of the Polish Academy of Sciences: Technical Sciences (for **100** points). It is a pity that the author did not include his achievements in the thesis.

4. Evaluation of the formal aspects of the thesis.
Ad. 4.

The dissertation consists of **67** pages, including the table of contents, which consists of **54** references, and an appendix with one table. It contains **7** chapters, **20** figures, **14** tables (excluding the **one** in the appendix), **24** listings and **15** equations In the further part of this dissertation, I will point out both the positive and negative features of the doctoral thesis in its further part.

5. Dissertation content.
Ad. 5.

As mentioned above - the thesis consists of **7** chapters. The **first** one provides introduction to the topic together with the history of games and some background about Artificial Intelligence. The **second** chapter contains more detailed theoretical background on Monte Carlo Tree Search algorithm and Reinforcement learning. The **third** chapter contains description of the LOTRCD's rules, together with some code listings. In the

fourth chapter the author described the process of MCTS agent developments. In the **fifth** chapter the proces of the RL agent development was presented. Chapter **sixth** contains information regarding conducted experiments with a (very brief) conclusions. The last - **seventh** chapter is the thesis summary. All chapters present original, innovative scientific problems' solution.

6. Positive qualities of the thesis.
Ad. 6.

The publication of the dissertation, unusual for doctoral dissertations, made a very positive impression. This may not be a substantive comment, but I rate the aesthetics of the project very highly. The described problem has been solved. Figures' and tables' quality is proper.

Based on the dissertation content the author showed the knowledge and ability to define a scientific problem, presented ways to solve it and experimentally verified the proposed methodology. Additionally, the PhD candidate authored and co-authored few, scientific papers with an impact factor, strongly related with with his scientific topic.

Also, the proposed topic is very interesting and innovative, thus, it describes a novel implementation of the game agent.

7. Negative aspects of the thesis.
Ad. 7.

Below my critical comments:
- The work is very short, even sparing, perhaps written in accordance with the principle "the less means more", which makes it seem careless.
- The dissertation does not emphasise the author's achievements, information about his publication achievements, possible awards or participation in scientific and research projects.
- The language of work is sometimes colloquial, which in my opinion does not suit the doctoral dissertation.
- Keywords do not reflect the content of the work.
- The division into chapters is more suitable for a scientific publication than for a doctoral dissertation.
- The titles of individual chapters do not fully reflect their content.
- The first chapter provides an introduction, but lacks a solid, thorough literature review, which negatively affects the reception of the entire work.
- Equations (5.4), (5.6) and (5.7) were incorrectly formulated. Please explain/correct these mistakes.
- The sixth chapter contains conclusions, but on less than half a page, which is not befitting a doctoral dissertation.
- There is also no separate discussion in which the author could include information on possible difficulties or problems, which would greatly contribute to its quality.
- The summary describes the achievements in detail, but without information about the theses defined earlier (at the opening of the doctoral dissertation), it was difficult to assess them.
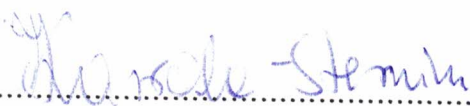
- The bibliography consists of only 54 items. This is a small number for a doctoral thesis, lower than that in many scientific publications! In addition, among the 54 bibliographic items, only 28 from the years 2017-2023 were included. With such an interesting topic - this part of the work should be more numerous.
- Information about the author's publications has not been separated in the bibliography, which is a pity.

8. **Summary assessment.**
Ad. 8.

Despite the short "list" of positives and the slightly longer list of negatives, the overall conclusion about the thesis is **positive**. To sum it all up, the candidate presents a thesis written in a very good English, although not always formal, which is not his first language. And in my opinion, the doctoral dissertation of **mgr inż. Konrad Godlewski** contains valuable research results and is an important scientific achievement in the development of **Technical Information Technology and Telecommunications (Informatyka Techniczna i Telekomunikacja),** and the developed research methodology and presented results make it important for the discipline. Moreover, taking into account the author's publication achievements, I believe that this dissertation meets all the requirements for works at this stage of education and may be the subject of public defence.

I recommend the work of Mr. Konrad Godlewski for defence.

Dr hab. inż. Aleksandra Kawala-Sterniuk