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# Review report
### of the doctoral dissertation by Konrad Godlewski, MSc, entitled:
*Monte Carlo Tree Search and Reinforcement Learning methods for multi-stage strategic card game*

The following review report is prepared on the basis of the resolution of the Scientific Council of the Discipline of Information and Communication Technology of the Warsaw University of Technology, of October 18, 2022 and was made in accordance with the meaning of the Act of 20 July 2018, the Law on Higher Education and Science.

## 1. Thematic scope of the dissertation

The thesis presents the implementation of an agent supporting the player in decisions made during The Lord of The Rings: The Card Game. The implementation of the game itself, without improvements to the existing solutions/algorithms, is a unique challenge due to the number of available expansions of the core set, and thus the huge number of cards involved in the game and the number of possible game scenarios. The game belongs to the group of collectible card games and is a cooperative Living Card Game.

The presented solutions include two methods: Monte Carlo Tree Search (MCTS) and Reinforcement Learning (RL). The first one is based on a heuristic search that uses random sampling of game states, while the latter one is based on a trial-and-error method in which the agent interacts with the environment. The Author proposes to extend the MCTR to include action reduction, which reduces the tree size thanks to elimination of cards with low utility value. In turn, due to the operation of the agent in an environment with a variable number of actions, the selection of RL algorithms was based on the method of coding actions. In the work, the author proposed two types of coding: macroactions, which allow to obtain a fixed number of actions, and direct actions, i.e. playing individual cards by the agent.

The proposed topic of the work is exceptionally interesting/innovative for several reasons. The first is the implementation of the game agent, which has not been implemented before and which is very extensive and presents a unique challenge. On the other hand, the gaming industry, apart from being very profitable, is a source of development of new technologies in areas such as optimization, artificial intelligence, machine learning and graphics processing, and so on.

## 2. Content of the dissertation

The dissertation has 67 pages, consists of 7 chapters and a list of literature used in the work, which includes 54 items.

The work can be somewhat unnaturally (because not according to the chapters) divided into two main parts. Chapters 1-3.3 introduce the scope of the work and present the concepts

necessary to understand the solutions presented in the following chapters. In turn, from the second part of chapter 3 (from 3.4) to chapter 7, proposed solutions are shown along with simulation results and discussion.

In the first chapter (Intruduction), the Author introduces the history of games along with their traditional division and the division of card games due to the mechanics of the game. In addition, this Chapter briefly describes the background of Artificial Intelligence in games. As the summary of this chapter the Author presents his goal and motivation. The goal is basically summed up in one sentence: *The thesis aims to verify whether AI agents can play successfully in the strategic card game The Lord of the Rings: The Card Game (LOTRCG).*

Second Chapter provides more detailed theoretical description of Monte Carlo Tree Search algorithm and Reinforcement learning. In Chapter 3 it is possible to read about the rules of the Lord of The Rings: The Card Game, but also Author provides here first codes of functions used further in the proposed solutions.

Chapters 5 and 6 present a full implementation of the MCTS and RL agents, while Chapter 7 presents the experiments. These 3 chapters are the Author's extremely valuable contribution to the dissertation. They not only present original solutions to the problem, but also show the Author's independent research.

## 3. Obtained results

The aim of the thesis was to verify whether AI agents can play successfully in the strategic card game The Lord of the Rings: The Card Game.

The Author's main achievements can be summed up as:

- action-reduction extension for MCTS method
- application of Reinforcement Learning algorithms in a partially observable environment with a varying number of actions
- methodology proposed in thesis makes use of random agents to identify the key decision stages in the game

The game consists of five decisions: planning, questing, travel, defense and attack, but there are only three crucial decisions which are made with use of MCTS or RL algorithms: planning, questing and defense. In Chapter 7 Author presents different configurations of random agent combined with MCTS or RL algorithms. Author uses correctly defined measures to show which of the proposed configurations are the best.

## 4. Detailed comments

There are some shortcomings in the reviewed dissertation, which can be summarized as follows:

1. An undoubted disadvantage of the work is the lack of explicitly defined theses. The dissertation is written like a scientific article, where the goal is defined, while in doctoral dissertations the emphasis is placed on theses, which are tried to be proved using the content included in the dissertation. In the summary it is possible to find detailed achievements of the Author described in the reviewed work, but these are also not theses.

*A. Św.*

2. Equation (5.6) seems to be written incorrectly, it seems to be an assignment, while an equation came out of it.

What is the difference between $s$ and $s_t$, $s_{t+1}$ and $s'$? The description does not directly imply that, and the names entered are 'state' and 'next state', so do they designate the same states? Perhaps creating an additional list of symbols at the beginning of the thesis would clarify the situation.

Equation (5.7) (because it is not a function) seems to be incomplete, since $\delta$ is a function, the notation $\delta(\cdot)$ should appear, taking into account what variables this function depends on.

Under equation (5.4) we can find: $\varphi$ *is trainable variables of the actor*; is $\varphi$ a vector? Are $\varphi$, $w$ and $v$ weights of the neural network?

Minor:

3. The structure of the thesis and the names of the chapters introduce a bit of chaos. For example, Chapter 3 is not only a description of the rules of the game, as the title suggests, but also introduces some algorithms that are used in further parts of the work.

4. On page 21, there is an information about simplifying the rules of the game; line 5 under the Table 3.1: *the game model does not take advantage of the card's unique abilities described in a game text (11 on Fig. 3.1)*, but there is no such item in this Figure.

5. Bibliography is a bit sloppy:
   – articles are missing DOI
   – for example position [11] and [28] are missing volume, issue and page numbers

To discuss:

6. Classes QNetwork, ActorNetwork and CriticNetwork use only Dense layers, have Author thought about using other layers at this stage? There is only information about motivation of using only one layer, in my opinion quite late in the thesis (few pages after defining these classes), but no information about trying to use other layers.

## 5. Summary - final evaluation

The reviewed doctoral dissertation presents the author's general theoretical knowledge in a given discipline, the ability to independently conduct scientific work and is an original solution to a scientific problem.

Despite some faults, in my opinion, the reviewed thesis fulfills all requirements posed on theses aimed for obtaining PhD degree. This thesis is ready to be defended orally, in front of respective committee.

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