Review of the PhD Thesis: Adaptive Control Algorithms of Intelligent Agents

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The thesis deals with the problem of design and development of adaptive methods for intelligent software agent's control. The author uses genetic programming and a tree-structured control mechanism to achieve this goal. Several original techniques are introduced and the proposed algorithms are thoroughly tested on experiments.

The main goal of the thesis is to evolve an agent's control mechanisms by adaptive algorithms. The main application area is the data mining field, where the goal of individual agents is to solve data mining tasks. Both multi-agent systems and data mining represent scientific topics which are developing and are a subject of great interest nowadays.

The submitted thesis is a revised version of the thesis submitted at the end of 2017. Therefore I will refer to revisions throughout my review to stress improvements.

The thesis is organised in two parts. First, there are "Introduction" and "Background and State of the Art". Second, there are 5 papers published by the author on international conferences and in a journal. The first part states the objectives, explains the current state of research and its problems, and also gives the ideas of the author's solutions to these problems. The second part brings more on the author's solutions and results of experiments.

The chapter "Introduction" was thoroughly rewritten since the last version. The problem definition in the original version was very brief. The section "The goal of presented thesis" was added and the individual sub-goals were described in more detail. Using the term sub-goals may give the reader impression, that the goal is scattered, but in this case, the sub-goals are related to each other and suggest the course of solution. The section "Problem definition" is much more informative than it was before (it contains also illustrative examples that were not needed on this stage).

I do not prefer to use a compilation of published papers as the main part of a thesis, since individual scientific papers repeat introductory information again and again, whereas some other parts may deserve more details. This is true for the presented thesis as well. On the other hand, it is an established practice and in this case it helps to follow the progress of the work in the course of individual papers. The revisions also include a better explanation of contributions of the individual papers and connection to goals defined in the chapter "Introduction".

The thesis is written in a comprehensible way, with a nice layout and almost without typos and grammar errors.

To achieve the goal of the thesis, the agent's control mechanism is represented by a tree structure, first representing polynomials only, then enhanced by the *if* statement. The tree structures are evolved using genetic programming. The focus is on advanced genetic operators, especially finding a suitable crossover appears to be challenging. The author proposes several similarity measures, in order to construct a crossover that exchanges similar subtrees and so causes smaller changes to the individual.

Both single criterion and multi-criteria optimisation are tested in the course of the work.

I would like to state following questions for the defense:

1. In the last experiment (comparison with auction techniques) – is there a possibility to compare the results with an optimal solution? What technique can be used to compute it for this problem?
2. You have mentioned the potential testing on real-world problem datasets. Can you give an example of such problem and dataset? What is the potential benefit of your approach applied to this real world problem?

Based on the above, I can conclude that the thesis of Ing. Martin Šlapák shows the achievement of standalone research work and contains original research results published by the author of this thesis. Despite the questionable quality of some publications of the author, I **do recommend** the dissertation for the defense.

In Prague, 7.5.2019

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Thesis Examiner Report

Author of the thesis: **Martin Šlapák**

Title of the thesis: **Adaptive control algorithms of intelligent agents**

The thesis focuses on an adaptive control algorithm of intelligent agents. The approach exploits the usage of adaptive algorithms, such as evolved decision trees or genetic programming, to design agents control mechanisms in situations, where a deterministic control algorithm is hard to define.

The goals of the thesis follow the application of evolving control from simple setting to more complex multi agent system with multiple criteria optimization. The problem to be solved by the multi agent system is bottom-up oriented task distribution. The final comparison of the presented approach with baseline task allocation technique is presented. The thesis primarily focuses on evolved agent control. The downside of the presented thesis is the lack of comparison with the multi agent task allocation and optimization approaches. The dissertation is based on the author's articles published between 2011 and 2017, so the up-to-dateness of the results is questionable. Almost half of the references are dated before 2000 and only 20 is post-2010.

The formal structure and organization of the dissertation suffer from the combination of the text and published articles. The completion of the dissertation objectives should be discussed in detail in the conclusion. The methods used in the dissertation are interesting and there provide scientific results in the field of genetic programming and subtree similarity problem for agent control. The applicability of the approach has been shown. However, it is not easy to assess the innovation of presented results and the progress beyond the state of the art. Some of the selected articles have been published on non-ranked or low-ranked conferences and in non-impacted low-rank journal. So, the quality of some of the results is not approved by a competitive review process.

The thesis is structured in the five main parts – introduction, background and SoTa, approach overview, and conclusion. First, the motivation and overview of the structure of the thesis is given together with the thesis goals definition. Second, the background overview presents a collection of concept descriptions, such as adaptive algorithms, multi-agent systems, computational intelligence and agent control. Third, the candidate approach overview is presented. Unfortunately, this part consists of short part of general approach overview and the collection of the published papers as experiment section. It should be beneficial to discuss the problem more formally and state the clear link to the applicability of the presented approach to the problem solved. Unfortunately, the experiments section presented as a set of published papers reduces the readability of the thesis. There are too many repeated parts and it is not easy to go through the results. Moreover, the problems solved in the individual articles differ, but there is missing a clear link to the complete story and the problem stated for the entire thesis in this chapter. Finally, the conclusion gives a complete overview of the results and discussion of future work.

Aside from the proposed approach and similarity measures, the contribution of the thesis lies in the experiments. Each of the five papers contains an experimental part evaluating the proposed algorithm. The experiments are rigorously processed and results are presented in figures to help to understand.

Based on the results presented in the thesis the idea of bottom-top oriented adaptive decision-making seems to be viable. The adaptive approach to decision making systems based on the evolution of trees fulfils the objectives of the thesis. The revisions made in the chapter "Conclusion" stress the contributions in the context of the goals defined at the beginning the thesis. There is still a lot left for future work, some of the problems are suggested in the conclusion.

Remarks and questions for the defense:

- My questions connected to the proposed approach were all satisfactorily answered during the previous defence.
- Are there any new approaches or methods that appeared during the last year and influenced the state-of-the-art of this field? Are there any consequences of them to the future work suggested in the conclusion?

I had reviewed also the original version of the thesis. My previous review was positive and since the revisions are mainly in the form of presentation, i.e. do not influence the achieved results or the factual content, I have no reason to change the conclusion.

The approach proposed in the thesis is non-trivial, new algorithms were defined and thoroughly tested on experiments. The results presented in five papers represent mature research on an international level. The text itself in its current form is more comprehensible (compared to the previous version) in the sense that it is easier to understand the goals and contributions of the presented work.

The author of the dissertation proved the ability to conduct research and achieve scientific results. In accordance with par. 47, letter(4) of the Law Nr. 111/1998 (The Higher Education Act) I do recommend the thesis for the presentation and defense with the aim of receiving the Ph.D. degree.

In Prague, April 18, 2019

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OPPONENT'S REVIEW OF THE DISSERTATION THESIS

ADAPTIVE CONTROL ALGORITHMS OF INTELLIGENT AGENTS

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Multi-agent systems (MAS) are a relatively new scientific discipline that has been developed since the early 1990s. MASs belong to the field of Artificial Intelligence (AI), whereas, as stated in Stone and Veloso (Multi-agent Systems: A Survey from a Machine Learning Perspective) they unify the principles of building complex systems based on multiple independent agents and mechanisms for coordinating their behavior.

The complexity of these systems requires finding new approaches to their optimal setup and optimal work. One of the possible approaches is also the use of evolutionary algorithms that allow you to search for optimal system setup but also to adapt it to the new situation. The presented work deals with the use of evolutionary algorithms (more precisely, using genetic programming) in this field and it is innovative and contributes to the field with new results.

Formal structure and organization of the dissertation

The work has two basic parts except introduction and conclusion: Background and state-of-the-art and Overview of authors principles. The main topic of the first part is a description the current state of the research and used methods in the area. The description is done systematically and in very good style.

The second part describes author's own approaches to solving the given problems and results published in five scientific articles. Five published scientific articles were reviewed and the results obtained are evaluated. It is possible to follow the gradual development of the scientific work of the author in the order of the articles processing. He gradually came to the new possibilities of realization of mutation and crossing operators, to new possibilities (new criteria) for trees in genetic programming. The disadvantage of the use of five articles is that some definitions and descriptions are repeated several times because each article needs to introduce the reader into the issue. But in the new form of the thesis I take it as advantage, the papers were reviewed and results compared.

From a formal point of view, I consider the work is exactly comprehensible, readable. A list of used references indicates that the author follows the latest trends in the area. The new template of the text and a reorganization of the text increases a quality of the PhD. thesis.

Assessment of the methods used in the dissertation

The author's theoretical approach to addressing MASs is based on genetic programming (GP) that works with graph structures (mainly with trees). Mutations and crossing operations are performed on the trees. In the course of the work, the author has confirmed that the crossing operator presents problems, but the mutation operator is appropriate and the options for refinement are indicated in the work. When investigating the crossover operation, he dealt with the similarity of trees in order to influence results of the crossing operator. He also introduced trees of higher degrees in which the "if" operator can be used.

Evaluation of the results and contribution for the defense

The experimental part of the thesis contains the results of experiments on large data sets, in each of five published articles. The evaluation of some of the experiments carried out is processed. The experimental part required a considerable time subsidy. The processing of experimental results is standard, graphical representation of the results contributes to their better understanding and comparison. The fifth scientific contribution regarding the decision-making strategies for auctions in computational multi-agent systems brings the interesting application of the proposed methods. Decision strategies are evaluated using trees found for computing agents.

Remarks, objections, notes, and questions for the defense

1. Why are relaxed trees important? Why it is not possible to exclude them from the population? What are your new considerations about using of isomorphic trees?
2. What programming and hardware means were used in the experiments? What representation of tree structures did you use in your systems?

The overall evaluation of the dissertation

In my opinion, this PhD thesis has scientific value and proves that extensive work has been done during PhD study. The thesis fulfills the demands required for a PhD-dissertation. It is devoted to the up-to-date problem of multi-agent systems. Five scientific papers prove that research contribution follows from the partially accomplished research. The goals oriented to explore of possibilities of design and development of adaptive methods of intelligent software agent's control were accomplished – so there is theoretical models and experimental results supported it.

The author of the dissertation proved the ability to conduct research and achieve scientific results. In accordance with par. 47, letter (4) of the Law Nr. 111/1998 (The Higher Education Act) I do recommend the thesis for the presentation and defense with the aim of receiving the Ph.D. degree.

In Košice, March 22, 2019

Gabriela Andrejková