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**REVIEW of PhD Thesis of Theofil Sidoruk, titled "State Space Reduction for Multi-agent Systems".**

This thesis deals with formal methods for the verification of multi-agent systems. These systems consist of several intelligent agents interacting with each other (and possibly with an external environment), sensing the behavior of other agents and taking actions in order to achieve their own goal. The importance of multi-agent systems resides on the fact that these systems, from driverless cars to multi-robot systems, are nowadays everywhere. Modern agents are becoming increasingly intelligent and sophisticated; they are often used in safety-critical situations where failure is clearly not an option. In this respect, formal methods offer useful tools to ensure system reliability. With a little more detail, to check whether a multi-agent system (M) meets a desired behavior goal (g), one can check whether e mathematical model of M (usually a game structure) satisfies a formal representation of the goal g (usually given as a temporal logic formula). Unfortunately, this approach suffers from the so called "state explosion problem", which is the major bottleneck in the practical application of formal methods in multi-agent system verification. This thesis introduces significant methods to reduce the state space modelling and, therefore, make the method feasible in practice. With the aim of showing the usefulness of the proposed approach, the thesis also provides practical approaches and benchmarks.

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The thesis is well written and organized. It has been a pleasure to read it. It consists of six chapters very well balanced, with a clear explanation of the content of each chapter and its purpose along the presentation of the achieved results. Precisely, Chapter 1 recalls the historical background of formal verification techniques, including model checking, and the issue of the state explosion problem. Chapter 2 introduces Asynchronous Multi-agent Systems (AMAS), as for models, and Alternating-time Temporal Logic (ATL*), as specification. Chapter 3 recalls the technique of partial order reduction (POR) and shows how this technique can be lifted to ATL*, both in the case of memoryless and memoryfull strategies, as well as for the epistemic extension of the logic. This chapter ends with an introduction to the well-known and a widely used open-source software verification tool SPIN, the related meta-language PROMELA used for building the models, and some experimental results. Chapter 4 discusses the model reduction techniques useful for security scenarios. To this aim, Attack-defense trees (ADTrees) are introduced, as well as two specific techniques for model reduction, namely the pattern- and layer-based, which allow to take advantage of specific model characteristics. Chapter 5 further works on ADTrees and introduces a methodology aiming to minimize the number of agents in a multi-agent system. Chapter 6 concludes the thesis and gives some interesting directions for future work.

The material of the thesis is novel and significant. The important venues where the papers containing the main results of this thesis appear further confirm this assessment. The proposed techniques definitely advance the research on practical applications of formal methods to the verification of large multi-agent systems.

As a constructive comment, I would suggest enlarging the related work part (along the chapters). Indeed, the thesis would have benefit on reporting more on related (both theoretical and practical) formal verification approaches of strategic reasoning involving other logics such as ATLsc and Strategy Logic, as well as their fragments.

In conclusion, **the dissertation fully meets the requirements for PhD thesis, and can be admitted to public defence**. Moreover, given the novelty and significance of the thesis material, and the fact that the proposed techniques undoubtedly contribute to the advancement of research in the practical applications of formal methods for verifying large multi-agent systems, I consider the dissertation outstanding and **recommend accepting it with honors**.

Best Wishes,

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