



Editorial

## Logic-Based Agent Verification

The multi-agent paradigm has become increasingly prevalent in computer science. Such popularity is due to its ability to capture social, economic, and other relevant interactions within a task. To meet the increasing demand for multi-agent systems, substantial progress has been made in theoretical, experimental and practical development.

Most recently, concerns have been raised regarding the trustworthiness of such systems. This issue is especially pertinent to military, aerospace, and commercial applications, but it also plays a role in numerous other applications. Recent swarm systems, with hundreds to thousands of agents, have increased the level of concern. The problem, in particular, is one of addressing the question of whether a collection of agents, while collaborating to satisfy a common goal, can be trusted to not only satisfy that goal but also satisfy additional safety-critical constraints. These constraints might arise from physical agent distances, required agent interactions with people, speed-of-response requirements, safety considerations in a manufacturing environment, or the need to ensure the security of classified information.

To address these issues, a small but growing community has evolved to study the problem in a formal context. Early work was presented at a series of workshops on *Formal Approaches to Agent-Based Systems (FAABS)* [5–7], as well as in the AAMAS conferences and relevant journals [2,3]. As an outgrowth of this early research, work on this topic has evolved into three main subtopics: formal agent modeling, formal verification of multi-agent systems, and applications research. The primary formalism that dominates the work is logic-based, and therefore the work fits well with the topic of this journal.

This special issue of the *Journal of Applied Logic* contains six papers on state-of-the-art research on the topic of assuring the trustworthiness of multi-agent systems. The collection of papers in this issue provides good coverage of the field, in the sense that the papers jointly span all three subtopics mentioned above and they are quite representative of the current state of the field.

The first three papers focus primarily on agent interaction protocols, and they address both the specification and verification of multi-agent systems. The paper entitled “Verifiable agent dialogues”, by Walton, develops a new multi-agent system (MAS) protocol language for multi-agent dialogues that is based on process calculus. This specification language is applicable to a wide range of agent architectures. In the latter half of the paper, a transformation is presented that enables the formal specifications to be translated into another language expressly designed for efficient and effective formal verification, based on *model checking*. *Model checking* consists of building a finite model of a (multi-agent) system and checking whether a desired property holds in that model [1]. In logic notation, model checking determines whether  $S \models P$  for model  $S$  and property  $P$ . In Walton’s paper, properties are expressed in linear temporal logic, and the MAS is based on the Belief-Desire-Intention (BDI) framework [4].

Giordano, Martelli, and Schwind’s paper, “Specifying and verifying interaction protocols in a temporal action logic”, has similar objectives to those of the Walton paper. In particular, they aim to specify and verify multi-agent interaction protocols. Verification is again based on model checking, although in this case it can be formalized as either a validity or a satisfiability problem. Giordano et al. present a logical specification framework that is based on dynamic linear-time temporal logic (DLTL), which is an extension of LTL. Following Singh [8], Giordano et al. adopt a social approach to agent communication. In this approach, communicative actions affect the “social state” of the

system, rather than the internal mental states of the individual agents. Social dynamics emerge from individual agent interactions.

Raimondi and Lomuscio describe an implemented system for model checking temporal, epistemic (knowledge-related), and deontic (obligation-related) properties of multi-agent systems. This work represents a substantial extension of previous model checkers, which typically deal with only temporal properties. They focus, in particular, on the data structures—ordered binary decision diagrams—which are used in the model checker to succinctly represent the inherently large state spaces involved in model checking, and describe how these data structures are used within the model checking algorithm.

The paper by Bontemps and Schobbens, entitled “The computational complexity of scenario-based agent verification and design”, overlaps the earlier papers in its concerns with formal specification and verification (via model checking) of interaction protocols. However its concerns diverge substantially into the area of computational complexity. Bontemps and Schobbens begin with the graphical, scenario-based *Agent Unified Modelling Language (AUML)*, and then address its inadequacies. First, they provide a formal semantics for AUML, which is a composition of temporal logic and game theoretic semantics. Then they analyze the complexity of AUML, simplify AUML to reduce its complexity, and then re-analyze. Unfortunately, it is discovered that even in the simplified and reduced version of AUML it is PSPACE-complete to check whether a society of agents obeys a protocol.

In “A verification framework for agent programming with declarative goals”, de Boer, Hindriks, van der Hoek, and Meyer seek to fill the gap between agent theory and practice. They build on agent programming languages, but allow declarative goals and their operationalization. De Boer et al. provide a temporal logic for goals, expressed using Hoare triples, thus providing the potential for agent verification.

Finally, this special issue includes a paper entitled “Security of multi-agent systems: A case study on comparison shopping” by Hutter, Mantel, Schaefer, and Schairer. Like the other papers in this special issue, this paper studies the flow of information between agents. However, it has an applications focus and is concerned, primarily, with security aspects and the potential loss of privacy in e-commerce scenarios. Specifically, it deals with preventing disclosure of confidential information to unauthorized meddlers. Furthermore, the primary theoretical results of this paper define an approach to the decompositional verification of security properties, i.e., a global security property can be decomposed into independently verifiable sub-properties, and the global verification of the entire system can be composed from these locally verified sub-properties.

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