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Intra-European Fellowships (IEF)

Call: FP7-PEOPLE-IEF-2008

Final Report

First-order Modal Logics for the Specification and Verification of Multi-Agent Systems

FoMMAS

Main Scientific Results

The objective of the FoMMAS project was to extend to a first-order setting the typical formalisms for the specification of multi-agent systems (MAS), i.e., epistemic and temporal modal logics. This was intended to open the way to new techniques for MAS verification by model checking. Our aim was to investigate the theoretical properties of these first-order MAS languages (axiomatisability, decidability, completeness, complexity), apply them to sophisticated scenarios from applications, and to develop a toolkit for automatic verification *via* model checking [7] The main objectives achieved by the FoMMAS project are as follows:

Objective 1 To develop first-order temporal epistemic languages for the specification of multi-agent systems, and to provide them with a computationally grounded semantics.

We introduced novel first-order temporal epistemic formalisms for specifying the behaviour of distributed and multi-agent systems. The methodology adopted consisted in extending to a first-order setting the typical MAS logics for model checking (i.e., the temporal logics CTL, LTL, etc.), endowed with epistemic operators for the agents in the system. More elaborated notions of knowledge, such as distributed and common knowledge have also been considered. Further, we provided a computationally grounded semantics to these quantified temporal epistemic logics by means of quantified interpreted systems (QIS), which naturally extend to the first-order the interpreted systems, the typical formalism for MAS [9].

Objective 2 Application of these formalisms to the analysis of critical MAS scenarios, such as communication and security protocols, web services.

We identified artifact systems [8] as an ideal application of the technology. These are a novel paradigm for specifying and implementing business processes described in terms of interacting modules called artifacts. Artifacts consist of data and lifecycle models, accounting for the relational structure of the artifact state and its possible evolutions over time. In [1, 2] we considered the problem of verifying artifact systems against specifications expressed in quantified temporal epistemic logic. This problem is in general undecidable. However, when artifact systems are deployed, their states can contain only a bounded number of elements. We exploited this fact to develop an abstraction technique that enables us to verify deployed artifact systems by model checking their bounded abstraction.

Objective 3 To study the theoretical properties of these MAS logics, i.e., axiomatisability, decidability, completeness, complexity.

We considered the theoretical properties of first-order temporal epistemic logics. Specifically, we have been able to provide sound and complete axiomatisations for a number of first-order modal logics. In [6] we gave a complete axiomatisation of a purely epistemic first-order logic under various constraints on the classes of corresponding QIS. Further, in [5, 3] we extended our quantified modal languages with temporal operators, showing that the axiomatisations available at the propositional level can be lifted to the first-order case, if no interaction between temporal and epistemic operators is assumed. Finally, in [4] we proved that axiomatisability can be retained even assuming some form of interaction between temporal and epistemic operators, whenever we limit quantification to a particular fragment of first-order modal logic: the *monodic fragment* [10]. Thus, we were able to single out expressive fragments of first-order temporal epistemic logic with important theoretical properties, namely axiomatisability.

Objective 4 Implementation of a toolkit.

Due to technical difficulties in some of the objectives above this objective was not fully achieved by the end of this project. However, a prototype is currently being produced and will be released by the end of 2011.

It is envisaged that the results achieved in this project will contribute to improve the design and verification of multi-agent systems, thus building more secure and reliable systems. In turn this will help improve the reliability of implementations of MAS systems including in e-commerce, e-business and e-government.

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