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Computational logic-based agents

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Computational logic provides a rigorous framework for designing, specifying, implementing and verifying autonomous agents that interact, communicate with one another and coordinate their activities in multi-agent systems and societies. In particular, computational logic can aid formalizing reasoning with agents' mental attitudes such as beliefs, desires, intentions and goals, and agents' social attitudes such as protocols, social commitments, obligations, norms and rules of behaviour. The use of computational logic aims at facilitating the development of agents that reason and act rationally while at the same time being able to verify the behaviour of these agents against their specification.

In the last decade, computational logic-based agents have gained popularity and many contributions have been made in this field both from a theoretical and a practical viewpoint. Computational logic has been used to provide powerful techniques and tools to address a number of issues in multi-agent systems, ranging from agent communication, to agent programming languages, to argumentation, to decision making in a single and multi-agent context, to applying model checking for verifying agent systems. The further development and integration of these techniques and tools shows promise for playing a fundamental role in developing powerful and verifiable agent-based systems.

This special issue is about using computational logic to deal with some key issues in multi-agent systems. The purpose is to report on recent developments in this area and discuss current challenges, limits, and future research opportunities. The problems discussed range from agent programming languages through a BDI agent-based programming language, to agent communication through a multi-issue bilateral negotiation, to logic programming-based agents realising a distributed abductive inference mechanism, to mental attitudes representation through a theory of intention representation, and automated, nondeterministic planning for extended reachability goals in agents.

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The papers included in this special issue were selected amongst 14 high-quality submissions.

The paper:

2APL: A Practical Agent Programming Language, by *Mehdi Dastani*

presents the syntax and an operational style semantics of 2APL, a BDI-based agent-oriented programming language. The language can be used to implement both multi-agent and individual agent programs. Both the specification of external environments and agents' access to these environments are considered. 2APL allows declarative and imperative programming styles where agents can represent, update, and reason about their mental states, and where processes, the flow of control, and mechanisms such as procedure calls can be specified. The paper also discusses the relation with existing computational-logic-based agent-oriented programming languages such as Jason, Jack, Jadex, 3APL, KGP, Minerva, and MetateMis.

The paper:

Logic-based Automated Multi-Issue Bilateral Negotiation in Peer-to-Peer E-marketplaces, by *Azzurra Ragone, Tommaso Di Noia, Eugenio Di Sciascio, and Francesco M. Donini*

addresses the problem of multi-issue bilateral negotiation in e-commerce settings by developing a logic-based agent communication language. This language extends propositional logic to model numerical and non-numerical issues and the relations among them. The paper presents a one-shot negotiation protocol, characterized by the intervention of a mediator which collects agents' preferences and proposes to each participant a fair Pareto-efficient agreement. The complexity of finding Pareto-efficient solutions as an optimization problem in the negotiation framework is proven to be NP-complete. The proposed framework has the advantage of mixing logic and utility theory in order to express agents' preferences in a qualitative and quantitative way.

The paper:

DARE: A System for Distributed Abductive REasoning, by *Jiefei Ma, Alessandra Russo, Krysia Broda and Keith Clark*

provides a mechanism for allowing agents to reason abductively (namely make hypotheses that fulfil given constraints) in a fully distributed way. Agents's beliefs and goals are represented as abductive logic programs, private to the agents themselves. Agents interact with other agents when their local reasoning does not suffice to solve their abductive tasks (these may correspond, e.g., to building a plan for their goals). The algorithm presented may be used, for example, to find joint plans amongst agents. The paper studies correctness properties of the proposed algorithm, presents a multi-agent architecture for implementing the algorithm, and briefly discusses an implementation of the architecture in QuProlog, an existing multi-threaded Prolog platform.

The paper:

Dynamic Intention Structures I: A Theory of Intention Representation, by *Luke Hunsberger and Charles L. Ortiz*

tackles the problem of representing agents' intentions that may be incomplete and mutually dependent. The paper starts by highlighting the limitations of existing theories in representing referred parameters in agents' plans during communication, and in distinguishing cases where agents are free to select the value of a parameter from cases where the agents' intentions involve some parameter whose value should be selected by some other agent. The problem

of representing the evolution of agents' intentions is also stressed. Then, the paper introduces a theory of intention representation that provides solutions to these representational limitations. This representational theory is based on a data structure called *Dynamic Intention Structure*. The authors define the semantics of the structures they introduce by providing a translation function that maps these structures onto logical formulas expressed in a first-order modal logic. Also, a dynamic-logic-style representation is provided to capture the evolution of agents' intentions.

Finally, the paper:

A Logic-based Agent that Plans for Extended Reachability Goals, by *Silvio Lago Pereira and Leliane Nunes de Barros*

introduces a new temporal logic called α-CTL to represent and reason about extended reachability goals through automated nondeterministic planning, along with a model checker based on fixpoint computations. Reachable goals specify a condition to be achieved at the end of the plan execution. Extended reachability goals are reachable goals that also specify a condition to be preserved during the plan execution. The paper argues about the inadequacy of using CTL logic to specify such goals. The α-CTL model checker is exploited to implement a planner capable of synthesizing reliable plans for extended reachability goals.

Concluding remarks

Overall, this special issue advances the state-of-the-art in computational logic-based agents by identifying and tackling a number of problems and emerging challenges, including the problems of:

- programming cognitive agents equipped with a variety of concepts and abstractions (including plans, beliefs, goals, and events),
- automating agent negotiation (and in particular multi-issue bilateral negotiation),
- distributing reasoning across agents (e.g., for finding joint plans),
- representing and reasoning with referenced and incompletely specified agents' intentions (in a collaborative setting), and
- planning for extended reachability goals (and verifying the plans using model checking).

The papers included in this special issue address these challenges using a variety of logic-based tools, namely BDI logic, logic programming, propositional logic, dynamic logic, first-order modal logic and an extension of CTL.

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