

Taming the Complexity of Linear Time BDI Logics

Nils Bulling
Clausthal University of Technology
bulling@in.tu-clausthal.de

Koen V. Hindriks
Delft University of Technology
k.v.hindriks@tudelft.nl

ABSTRACT

Reasoning about the mental states of agents is important in various settings, and has been recognized as vital for teamwork. But the complexity of some of the more well-known agent logics that facilitate reasoning about mental states prohibits the use of these logics in practice. An alternative is to investigate fragments of these logics that have a lower complexity but are still expressive enough for reasoning about the mental states of (other) agents. We explore this alternative and take as our starting point the linear time variant of BDI logic (BDI_{LT}). We summarize some of the relevant known complexity results for e.g. LTL , KD45_{LT} , and BDI_{LT} itself. We present a tableau-based method for establishing complexity bounds, and provide a map of the complexity of (various fragments of) BDI_{LT} . Finally, we identify a few fragments that may be usefully applied for reasoning about mental states.

Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence—*Multiagent Systems*; I.2.4 [Artificial Intelligence]: Knowledge Representation Formalisms and Methods—*Modal logic*

General Terms

Theory, Verification

Keywords

reasoning about mental states, linear time BDI logic, satisfiability, complexity

1. INTRODUCTION

In a social context, and more specifically for teamwork, the ability of an agent to reason about other agents has been recognized as vital [7]. In particular, reasoning about ones own and the mental states of other agents is important to be successful in such contexts. Reasoning about the mental states of others is needed to establish joint commitments and joint intentions [17, 4], collaboration and cooperation [17], teamwork [4, 7, 20], and coordination more generally [8].

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One application area is socio-cognitive robotics and human-robot teamwork [15], where modeling of social behavior is needed and it has been recognized that “consideration of the knowledge, abilities, goals, and even feelings of others” is required.

In practice, however, little use is made of logical approaches such as [4, 18, 9] that support reasoning about mental states due to the inherent complexity of the logics. For example, the satisfiability problem for agent dynamic logic, a logic closely related to the KARO framework, is in 2EXPTIME [19] and for the TEAMLOG framework including group attitudes as well as propositional dynamic logic it is EXPTIME -complete [9]. Practical approaches typically do not maintain many of the formal properties of mental attitudes, and, as noted in [11], “the need for high-level logic-based languages capturing the key components of the BDI model remains.” This problem has also motivated the work reported in [9]. More generally, the issue is related to “the gap between theory and practice” [21] since complexity bounds at least theoretically determine what can be done in principle to bridge this gap. In practice, agent platforms typically have been restricted to reason with the beliefs and goals of a single agent [2, 3] and do not allow reasoning about the beliefs and goals of other agents, e.g. having a belief about the goal of another agent. Identifying such extended fragments therefore is important as it may allow the use of logical fragments in practice for reasoning about other agents.

One approach to deal with this problem is to study and identify fragments of agent logics that have a lower complexity but still support reasoning about other agents’ mental states. There are general techniques for identifying such fragments and reducing the complexity. For example, it is known that restricting the number of propositional atoms used or the depth of modal nesting may reduce the complexity of a modal logic [12]. It is not cognitively plausible either that humans use unlimited depth of reasoning [7].

The problem we explore in this paper is the satisfiability problem of fragments of BDI_{LT} . We present a tableau-based proof method for a family of BDI_{LT} . The tableau-method can also be used to analyze the complexity of this family and we show BDI_{LT} is in PSPACE . We then explore which fragments have a significantly lower complexity than full linear time BDI logic. More specifically, the aim is to identify fragments for which the satisfiability problem is in NP . Identifying such fragments is a first step towards establishing reasonable computational performance as typical problem instances may be easier to solve [13], and, as even satisfiability for propositional logic is an NP -complete prob-

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