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$_{LTL}$**). We summarize some of the relevant known complexity results for e.g. **LTL**, **KD45$_n$**, and **BDI$_{LTL}$** itself. We present a tableau-based method for establishing complexity bounds, and provide a map of the complexity of (various fragments of) **BDI$_{LTL}$**. 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$_{LTL}$**. We present a tableau-based proof method for a family of **BDI$_{LTL}$**. The tableau method can also be used to analyse the complexity of this family and we show **BDI$_{LTL}$** 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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Taming Logics:

Handbook of Philosophical Logic Dov M. Gabbay,Franz Guenthner,2013-06-29 It is with great pleasure that we are presenting to the community the second edition of this extraordinary handbook It has been over 15 years since the publication of the first edition and there have been great changes in the landscape of philosophical logic since then The first edition has proved invaluable to generations of students and researchers in formal philosophy and language as well as to consumers of logic in many applied areas The main logic artiele in the Encyelopaedia Britannica 1999 has described the first edition as the best starting point for exploring any of the topics in logic We are confident that the second edition will prove to be just as good The first edition was the second handbook published for the logic commu nity It followed the North Holland one volume Handbook 0 Mathematical Logic published in 1977 edited by the late Jon Barwise The four volume Handbook 0 Philosophical Logic published 1983 1989 came at a fortunate temporal junction at the evolution of logic This was the time when logic was gaining ground in computer science and artificial intelligence cireles These areas were under increasing commercial press ure to provide devices which help and or replace the human in his daily activity This pressure required the use of logic in the modelling of human activity and organisa tion on the one hand and to provide the theoretical basis for the computer program constructs on the other **Multi-Dimensional Modal Logic** Maarten Marx,Yde Venema,2012-12-06 Modal Logic is a branch of logic with applications in many related disciplines such as computer science philosophy linguistics and artificial intelligence Over the last twenty years in all of these neighbouring fields modal systems have been developed that we call multi dimensional Our definition of multi dimensionality in modal logic is a technical one we call a modal formalism multi dimensional if in its intended semantics the universe of a model consists of states that are tuples over some more basic set This book treats such multi dimensional modal logics in a uniform way linking their mathematical theory to the research tradition in algebraic logic We will define and discuss a number of systems in detail focusing on such aspects as expressiveness definability axiomatics decidability and interpolation Although the book will be mathematical in spirit we take care to give motivations from the disciplines mentioned earlier on *Incomplete Information: Structure, Inference, Complexity* Stephane P. Demri,Ewa Orlowska,2013-04-18 The construction of any broadly understood theory of information or infor mation processing system involves two major methodological processes 1 abstraction and analysis 2 reasoning and computing This monograph is a realisation of these two processes in relation to the study of incompleteness of information The paradigm we are working with is inspired by a rough set approach to data analysis the formalisms we develop enable the use of a non invasive data representation This means that the only information which is and must be used in the process of analysis is the actual information that is to be analysed we do not require any additional sources of information An abstraction is formed in the process of conception design and develop ment of structures Then analysis leads to a selection of a class of structures In this book we delineate a class of informational structures that enable us to represent both numerical

and non numerical information and we analyse var ious manifestations of its incompleteness We discuss several general types of incompleteness of information which are grounded in a rough set style view of imprecision and uncertainty Manifestations of these types of incompleteness in information systems are investigated *Modal Logic* Patrick Blackburn,Maarten de Rijke,Yde Venema,2001 This is an advanced 2001 textbook on modal logic a field which caught the attention of computer scientists in the late 1970s Researchers in areas ranging from economics to computational linguistics have since realised its worth The book is for novices and for more experienced readers with two distinct tracks clearly signposted at the start of each chapter The development is mathematical prior acquaintance with first order logic and its semantics is assumed and familiarity with the basic mathematical notions of set theory is required The authors focus on the use of modal languages as tools to analyze the properties of relational structures including their algorithmic and algebraic aspects and applications to issues in logic and computer science such as completeness computability and complexity are considered Three appendices supply basic background information and numerous exercises are provided Ideal for anyone wanting to learn modern modal logic *Brinkman's cumulatieve catalogus van boeken* ,1996 Voorts een alphabetische lijst van Nederlandsche boeken in Belgi uitgegeven *Logic at Work* Helena Rasiowa,1999 The book is divided into eight parts whose topics are chosen to emphasize application areas of logic in particular those related to soft computing Each part demonstrates possible application of logical methods to problems in the respective areas The book presents a broad variety of fields and issues in which logic provides conceptual technical or methodological tool In particular important topics in foundations of soft computing including fuzzy logic multiple valued logic theories of inconsistency and ambiguity theory of rough sets theories of incomplete information are studied The book may be seen as a resource to which readers can turn for research horizons and ideas on how logical models and methods can be developed and applied It is a source for anyone who needs broad perspective on a role of applied logic and a better understanding of logical methods and their applications All the contributions present new and original results **Mathematical Reviews** ,2007 **Automated Software Engineering** ,1997 Logic and Language Antony Flew,1953 Logics II James Hill Parker,1992 The author attempts to link the social and biological sciences in a new way It appears that there are Social Logics which are cross cultural and seem to have a biological substrate This book shows how the biological baseline can be used for research into social cultural and other forms of organization It includes three case studies which use Logics Analysis to illustrate how this method can be successfully applied to group structure and process Parker discusses evidence for Social Logics through principles of language art myth literature and music Contents The Social Logics Paradigm Issues about Interpretation and Method Social Logics Analysis of Real Situations Conclusion **Brinkman's catalogus van boeken en tijdschriften** ,1996 With 1901 1910 1956 1960 Repertoium is bound Brinkman s Titel catalohus van de gedurende 1901 1910 1956 1960 Title varies slightly *Shakespeare's Comedy of the Taming of the Shrew* William Shakespeare,Sir Israel Gollancz,1898 **Comedy of The**

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