

Taming the Complexity of Linear Time BDI Logics

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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-

Taming Logics

Wojciech Penczek, Andrzej Szalas



Taming Logics:

Handbook of Spatial Logics Marco Aiello, Ian Pratt-Hartmann, Johan van Benthem, 2007-09-04 The aim of this handbook is to create for the first time a systematic account of the field of spatial logic The book comprises a general introduction followed by fourteen chapters by invited authors Each chapter provides a self contained overview of its topic describing the principal results obtained to date explaining the methods used to obtain them and listing the most important open problems Jointly these contributions constitute a comprehensive survey of this rapidly expanding subject Handbook of

Philosophical Logic Dov M. Gabbay, Franz Guenther, 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 article in the Encyclopaedia 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 community It followed the North Holland one volume Handbook of Mathematical Logic published in 1977 edited by the late Jon Barwise The four volume Handbook of 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 circles These areas were under increasing commercial pressure 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 organisation 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

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knowledge representation and automated deduction **Mathematical Foundations of Computer Science 1996** Wojciech Penczek, Andrzej Szalas, 1996-08-07 This book constitutes the refereed proceedings of the 21st International Symposium on Mathematical Foundations of Computer Science MFCS 96 held in Crakow Poland in September 1996 The volume presents 35 revised full papers selected from a total of 95 submissions together with 8 invited papers and 2 abstracts of invited talks The papers included cover issues from the whole area of theoretical computer science with a certain emphasis on mathematical and logical foundations The 10 invited presentations are of particular value **Modal Logic** Patrick Blackburn, Maarten de Rijke, Yde Venema, 2002-08-22 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 **Relation Algebras by Games** Robin Hirsch, Ian Hodkinson, 2002-08-15 Relation algebras are algebras arising from the study of binary relations They form a part of the field of algebraic logic and have applications in proof theory modal logic and computer science This research text uses combinatorial games to study the fundamental notion of representations of relation algebras Games allow an intuitive and appealing approach to the subject and permit substantial advances to be made The book contains many new results and proofs not published elsewhere It should be invaluable to graduate students and researchers interested in relation algebras and games After an introduction describing the authors perspective on the material the text proper has six parts The lengthy first part is devoted to background material including the formal definitions of relation algebras cylindric algebras their basic properties and some connections between them Examples are given Part 1 ends with a short survey of other work beyond the scope of the book In part 2 games are introduced and used to axiomatise various classes of algebras Part 3 discusses approximations to representability using bases relation algebra reducts and relativised representations Part 4 presents some constructions of relation algebras including Monk algebras and the rainbow construction and uses them to show that various classes of representable algebras are non finitely axiomatisable or even non elementary Part 5 shows that the representability problem for finite relation algebras is undecidable and then in contrast proves some finite base property results Part 6 contains a condensed summary of the book and a list of problems There are more than 400 exercises The book is generally self contained on relation algebras and on games and introductory text is scattered throughout Some familiarity with elementary aspects of first order logic and set theory is assumed though

many of the definitions are given Chapter 2 introduces the necessary universal algebra and model theory and more specific model theoretic ideas are explained as they arise

Cylindric-like Algebras and Algebraic Logic Hajnal Andréka, Miklós Ferenczi, István Németi, 2014-01-27 Algebraic logic is a subject in the interface between logic algebra and geometry it has strong connections with category theory and combinatorics Tarski's quest for finding structure in logic leads to cylindric like algebras as studied in this book they are among the main players in Tarskian algebraic logic Cylindric algebra theory can be viewed in many ways as an algebraic form of definability theory as a study of higher dimensional relations as an enrichment of Boolean Algebra theory or as logic in geometric form cylindric in the name refers to geometric aspects Cylindric like algebras have a wide range of applications in e.g. natural language theory data base theory stochastics and even in relativity theory The present volume consisting of 18 survey papers intends to give an overview of the main achievements and new research directions in the past 30 years since the publication of the Henkin Monk Tarski monographs It is dedicated to the memory of Leon Henkin

Logic Colloquium '96 J. M. Larrazabal, D. Lascar, G. Mints, 2017-03-02 Proceedings of the 1996 European Summer Meeting of the Association for Symbolic Logic held in San Sebastian Spain

Models, Algorithms, Logics and Tools Luca Aceto, Giorgio Bacci, Giovanni Bacci, Anna Ingólfssdóttir, Axel Legay, Radu Mardare, 2017-08-17 This Festschrift is published in honor of Kim Guldstrand Larsen one of the earliest precursors of computer science in Denmark on the occasion of his 60th birthday During the last three decades Kim Guldstrand Larsen has given major contributions across a remarkably wide range of topics including real time concurrent and probabilistic models of computation logic in computer science and model checking Since 1995 he has been one of the prime movers behind the model checking tool for real time systems UPPAAL for which he was a co recipient of the CAV Award in 2013 The Festschrift contains 32 papers that feature the broad range of Kim Guldstrand Larsen's research topics such as formal languages and automata theory logic verification model checking and testing algorithmic game theory and mechanism design semantics and reasoning real time and distributed systems and modeling and simulation

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web may 14 2022 dear god we come before you today to celebrate the graduation of our preschool children we thank you for their wisdom their patience and their love may they continue to grow in your grace and joy as they enter the world of kindergarten

7 helpful prayers for kindergarten graduation - Jun 03 2023

web jun 21 2023 short prayer for kindergarten graduation heavenly father what a beautiful day today i m witnessing a new crop of kindergarten children graduating it is a special moment of a great milestone in the lives of these young ones they have all worked tirelessly to achieve this feat i commit them to you this day

prayer for graduation day preschool - Jan 30 2023

web prayer for graduation day preschool let us unite our hearts in prayer and entrust to the hands of the lord those who will be graduated tomorrow may god who began this good work in you carry it through to completion enabling you to use your talents to the fullest may god give you the grace to make wise choices

5 pious prayers for kindergarten students prayers - Feb 16 2022

web holy lord god please extend your power and grace to this sweet child heading to kindergarten watch over them with your mindful eyes keep them safe from harm and hurt help this child to be a generous and loving classmate teach them to be helpful to their classmates guide them with the inspiration to share and listen and learn

prayer for graduation - May 22 2022

web prayer for graduation dear lord may this graduation day be a celebration of your life within us we give you all the learning the skills and the hard work of these years we pour out our gifts into your hands may we hold this memory in our heart as we continue on our adventure father may we live a life that reveals your hope and be guided

prayers for my girl on your kindergarten graduation lafayette - Dec 29 2022

web may 8 2018 prayers for my girl on your kindergarten graduation sweet lillian we ve come a long way this kindergarten

year you and i have learned so much we ve grown we ve cried and we ve moved bedtime around to find the right fit more importantly we ve succeeded in passing your first year of school you re ready for first grade and

opening prayer des moving up kindergarten class 2022 - Mar 20 2022

web jun 27 2022 prayerful kindergarten students delivering the opening prayer in des moving up ceremony virtual graduation ryvent ezekiel l arellano and qwynnyll o ro

7 prayers for preschool graduation grace and prayers - Sep 06 2023

web concluding thoughts short preschool graduation prayer for preschoolers dear lord we thank you for all the time we have spent together this year thank you for allowing all of us the ability to nurture these children in your name father we ask that you watch over these graduating preschoolers walk with them lord down their new paths

prayer for preschool graduation ceremony - Apr 01 2023

web amen almighty god thank you for the wonderful time we have had learning and studying here

15 opening prayers for graduation ceremony 2023 - Nov 27 2022

web sep 5 2023 conditions for inclusion of divine petitions 15 opening prayers for graduation ceremony 1 a prayer for new beginnings 2 a prayer for guidance 3 a prayer of thanksgiving 4

15 awesome prayers for kindergarten students - Jun 22 2022

web sep 2 2023 prayer for a joyful learning environment isaiah 54 13 niv all your children will be taught by the lord and great will be their peace dear god i invite your presence into the kindergarten classrooms where my kid learns daily asking that you transform them into spaces of joy growth and wonder

prayer for preschool students - Jul 24 2022

web prayer for preschool students dear god today i come to you in prayer lord asking you to help my child ren experience peace this year i pray he she they will not worry about things they cannot control but that you will guard his her their hearts and minds and keep him her them trusting in you i pray he she they will not only enjoy the

graduation opening prayer trinity school of durham and - Sep 25 2022

web please pray with me our father god how wonderful are the works of your hands as we gather here today to celebrate a step forward into new places with new people and new experiences let us not forget the blessings that follow behind us for this school which graduation opening prayer created date