

# A Framework for Reasoning about Rational Agents

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## ABSTRACT

We propose an extension of alternating-time temporal logic, that can be used for reasoning about the behavior and abilities of agents under various rationality assumptions.

## 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

## Keywords

multi-agent systems, game theory, temporal logic, rationality

## 1. INTRODUCTION

*Alternating-time temporal logic* (ATL) [1] is a temporal logic that incorporates some basic game theoretical notions. In this paper, we extend ATL with a notion of *plausibility*, which can be used to model and reason about rational behavior of agents. In our approach, some strategies (or rather *strategy profiles*) can be assumed plausible, and one can reason about what can be *plausibly* achieved by agents under such an assumption.

This idea has been inspired by the way in which games are analyzed in game theory. First, game theory identifies a number of *solution concepts* (e.g., Nash equilibrium, undominated strategies, Pareto optimality) that can be used to define rationality of players. Then, we usually *assume* that *players play rationally* in the sense of one of the concepts, and we *ask* about the *outcome of the game under this assumption*. Note that solution concepts do not only help to determine the right decision for “our” agent. Perhaps even more importantly, they constrain the possible (predicted) responses of the opponents. For many games the number of all possible outcomes is infinite, although only some of them “make sense”. Still, we need a notion of rationality (like subgame-perfect Nash equilibrium) to

discard the “less sensible” ones, and determine what should happen had the game been played by ideal players.

There are two possible points of focus in this context. Research within game theory understandably favors work on *characterization* of various types of rationality (and defining most appropriate solution concepts). Applications of game theory, also understandably, tend toward using the solution concepts to predict the outcome in a given game (i.e., to “solve” the game). The first issue has been studied in the framework of logic, for example in [2, 4, 10, 11]; more recently, game-theoretical solution concepts have been characterized in dynamic logic [7], dynamic epistemic logic [3], and ATL [13, 8]. The second issue seems to have been neglected in logic-based research: papers by Van Otterloo and his colleagues [14, 16, 15] are the only exceptions we know of (and each of them commits to a particular view of rationality). Here, we try to fill in this gap, and propose a general, modal logic-based framework for reasoning about behavior and abilities of rational agents.

## 2. ATL

The language of Alternating-time Temporal Logic [1] is defined over a set  $\text{Agt}$  of agents and a set  $\Pi$  of propositions, and consists of the following formulae:

$$\varphi ::= p \mid \neg\varphi \mid \varphi \wedge \psi \mid \langle A \rangle \gamma, \quad \gamma ::= \bigcirc \varphi \mid \Box \varphi \mid \varphi U \psi,$$

where  $p \in \Pi$  and  $A \subseteq \text{Agt}$ . Informally,  $\langle A \rangle \varphi$  says that agents  $A$  have a collective strategy to enforce  $\varphi$ . ATL formulae include the usual temporal operators:  $\bigcirc$  (“in the next state”),  $\Box$  (“always from now on”) and  $U$  (strict “until”). Additionally,  $\bigcirc$  (“now or sometime in the future”) can be defined as  $\bigcirc \varphi \equiv \top U \varphi$ .

The semantics of ATL is defined in *concurrent game structures*:

$$M = (\text{Agt}, Q, \Pi, \pi, \text{Act}, d, \alpha),$$

consisting of: a set  $\text{Agt} = \{1, \dots, k\}$  of agents; set  $Q$  of states; set  $\Pi$  of atomic propositions; valuation of propositions  $\pi : Q \rightarrow P(\Pi)$ ; set  $\text{Act}$  of actions. Function  $d : \text{Agt} \times Q \rightarrow P(\text{Act})$  indicates the actions available to agent  $a \in \text{Agt}$  in state  $q \in Q$ . A move vector in state  $q$  is a tuple  $\langle m_1, \dots, m_k \rangle \in d(q)$  where  $d(q) = \prod_{a \in \text{Agt}} d_a(q)$  is the set of all move vectors in  $q$ . Finally,  $\alpha$  is a transition function which maps a state  $q \in Q$  and a move vector  $\langle m_1, \dots, m_k \rangle \in d(q)$  to another state  $q' = \alpha(q, \langle m_1, \dots, m_k \rangle)$ .

A *computation* or *path*  $\lambda = q_0, q_1, \dots$  is an infinite sequence of states such that there is a transition between each  $q_i, q_{i+1}$ . We define  $\lambda[i] = q_i$  to denote the  $i$ -th state of  $\lambda$ .  $\lambda_{\text{Agt}}$  denotes all paths of  $M$ . The set of all paths, starting in  $q$ , is given by  $\lambda_{\text{Agt}}(q)$ .

A (memoryless) strategy of agent  $a$  is a function  $s_a : Q \rightarrow \text{Act}$  such that  $s_a(q) \in d_a(q)$ . The set of strategies for agent  $a$  is denoted by  $\Sigma_a$ . A collective strategy  $s_A$  for team  $A \subseteq \text{Agt}$  specifies an individual strategy for each agent  $a \in A$ . Now,  $\Sigma_A =$

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# Reasoning About Rational Agents

**John L. Pollock**



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**Reasoning about Rational Agents** Michael J. Wooldridge, 2000 One goal of modern computer science is to engineer computer programs that can act as autonomous rational agents software that can independently make good decisions about what actions to perform on our behalf and execute those actions Applications range from small programs that intelligently search the Web buying and selling goods via electronic commerce to autonomous space probes This book focuses on the belief desire intention BDI model of rational agents which recognizes the primacy of beliefs desires and intentions in rational action The BDI model has three distinct strengths an underlying philosophy based on practical reasoning in humans a software architecture that is implementable in real systems and a family of logics that support a formal theory of rational agency The book introduces a BDI logic called LORA Logic of Rational Agents In addition to the BDI component LORA contains a temporal component which allows one to represent the dynamics of how agents and their environments change over time and an action component which allows one to represent the actions that agents perform and the effects of the actions The book shows how LORA can be used to capture many components of a theory of rational agency including such notions as communication and cooperation

*Foundations of Rational Agency* Michael Wooldridge, A. Rao, 2013-03-09 Over the past decade rational agency has come to be recognised as a central theme in artificial intelligence Drawing upon research on rational action and agency in philosophy logic game theory decision theory and the philosophy of language this volume represents an advanced comprehensive state of the art survey of the field of rational agency as it stands today It covers the philosophical foundations of rational agency logical and decision theoretic approaches to rational agency multi agent aspects of rational agency

including speech acts joint plans and cooperation protocols and finally describes a number of approaches to programming rational agents Although written from the standpoint of artificial intelligence this interdisciplinary text will be of interest to researchers in logic mainstream computer science the philosophy of rational action and agency and economics *ECAI 2004* Ramon López de Mántaras, Lorenza Saitta, 2004 This is the Golden Age for Artificial Intelligence The world is becoming increasingly automated and wired together This also increases the opportunities for AI to help people and commerce Almost every sub field of AI had now been used in substantial applications Some of the fields highlighted in this publication are CBR Technology Model Based Systems Data Mining and Natural Language Techniques Not only does this publication show the activities capabilities and accomplishments of the sub fields it also focuses on what is happening across the field as a whole

Computational Logic in Multi-Agent Systems Fariba Sadri, 2008-10-23 This book constitutes the thoroughly refereed post conference proceedings of the 8th International Workshop on Computational Logic for Multi Agent Systems CLIMA VIII held in Porto Portugal in September 2007 co located with ICLP 2008 the International Conference on Logic Programming The 14 revised full technical papers and 1 system description paper presented together with 1 invited paper were carefully selected from 33 submissions and went through at least two rounds of reviewing and improvement The regular papers address topics such as interdependencies and co ordination of task based planning in multi agent systems interval temporal logic game theoretic concepts for reasoning about rational agents proof theory for multi agent epistemic logic transformational semantics for evolving logic programs EVOLP programming languages based on BDI models agent oriented early requirements engineering framework heuristic algorithms for agent negotiation as well as argumentation **Innovative**

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Evidence VIII Policy The volume is essential reading for students and researchers in economics and philosophy who are interested in exploring the interconnections between the two disciplines It is also a valuable resource for those in related fields like political science sociology and the humanities *Cognitive Carpentry* John L. Pollock,1995 A sequel to the author's *How to Build a Person* this work builds upon that theoretical groundwork for the implementation of rationality through artificial intelligence It argues that progress in AI has stalled because of its creators reliance upon unformulated intuitions about rationality Instead the author bases the OSCAR architecture upon an explicit philosophical theory of rationality encompassing principles of practical cognition epistemic cognition and defeasible reasoning One of the results is the first automated defeasible reasoner capable of reasoning in a rich logical environment **Agent and Multi-Agent Systems:**

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the Modern Age from semantics to linguistics and proof theory from the discussion of technical problems to deep metaphysical questions and in it the history of logic is kept in dialogue with the history of mathematics economics and the moral sciences at large



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## **Table of Contents Reasoning About Rational Agents**

1. Understanding the eBook Reasoning About Rational Agents
  - The Rise of Digital Reading Reasoning About Rational Agents
  - Advantages of eBooks Over Traditional Books
2. Identifying Reasoning About Rational Agents
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Reasoning About Rational Agents
  - User-Friendly Interface
4. Exploring eBook Recommendations from Reasoning About Rational Agents
  - Personalized Recommendations
  - Reasoning About Rational Agents User Reviews and Ratings
  - Reasoning About Rational Agents and Bestseller Lists

5. Accessing Reasoning About Rational Agents Free and Paid eBooks
  - Reasoning About Rational Agents Public Domain eBooks
  - Reasoning About Rational Agents eBook Subscription Services
  - Reasoning About Rational Agents Budget-Friendly Options
6. Navigating Reasoning About Rational Agents eBook Formats
  - ePub, PDF, MOBI, and More
  - Reasoning About Rational Agents Compatibility with Devices
  - Reasoning About Rational Agents Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Reasoning About Rational Agents
  - Highlighting and Note-Taking Reasoning About Rational Agents
  - Interactive Elements Reasoning About Rational Agents
8. Staying Engaged with Reasoning About Rational Agents
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Reasoning About Rational Agents
9. Balancing eBooks and Physical Books Reasoning About Rational Agents
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Reasoning About Rational Agents
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Reasoning About Rational Agents
  - Setting Reading Goals Reasoning About Rational Agents
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Reasoning About Rational Agents
  - Fact-Checking eBook Content of Reasoning About Rational Agents
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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