# Representing and Reasoning about Game Strategies

# (Doctoral Consortium)

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## ABSTRACT

This paper states the challenges for modeling and reasoning strategic behaviour of agents in multi-agent systems. After a brief review of logical analysis of games, we specify the problem we are tackling, and then briefly outline our research plan, the results we have achieved to date as well as the ongoing directions.

## Keywords

Multi-agent system; strategic reasoning; game theory; social choice

## 1. INTRODUCTION

Game theory is to study strategic decision making, and analyze situations where the final outcome is not only up to your choices, but also depends on the choices of others. The ultimate goal of the theory is to predict the behaviour of rational agents and prescribe a plan of actions that need to be adopted. Therefore, the theory includes modelling theory as well as various solution concepts, which aim to predict the behaviour of agents and prescribe what rational players should do. However, as Johan van Benthem points out, "much of game theory is about the question whether strategic equilibria exist. But there are hardly any explicit languages for defining, comparing, or combining strategies" [6].

This problem also challenges the designing of game-playing agents in artificial intelligence. The design and study of distributed and multi-agent systems typically has to deal with agents who have a choice of actions to perform, and have individual and possibly conflicting goals. This makes agents act strategically, attempting to select their actions so as to guarantee their goals even in face of other agents' actions. This concern has motivated the development of a variety of strategic logics that aim to model and reason about strategic behaviour of agents in multi-agent systems. These frameworks provide description languages and inference mechanisms for strategies in game playing.

In general, logical analysis of games mainly deals with three problems: (1). *how to specify a game situation*, (2). *how to represent a game strategy* and, more importantly, (3). *how to model strategic reasoning of game players*. However, to our best of knowledge, so far there has been no unified framework to address the three problems within a single logic. For instance, logics to describe games and represent strategies such as game description logic [10], do not have the facility for reasoning about strategies, while logics to reason about strategies use existential quantifiers to say "players have a strategy" for achieving some results without specifying what the strategy is, since descriptions of the strategy itself are beyond the expressivity of the logical language [8]. This is actually a serious problem because without explicitly specifying game rules, without expressing the strategies under consideration, we are unable to reason about the effects of these strategies and discover the characteristics of strategic reasoning. Thus, a comprehensive logical language and associated inference mechanism to specify game rules, represent game strategies and reason about game strategies is desirable in multi-agent systems.

## 2. RESEARCH PLAN

In this research, we focus on establishing a logical formalism for modelling games, representing strategies, and developing an inference mechanism for reasoning about strategies. There is a good reason to suppose that the logic-based formalisms will be of value in representing and reasoning about game strategies. Firstly, this logical and declarative scheme is commonly used in the knowledge representation community [9]. They can be used together with tools and techniques developed in AI and computer science. For instance, as query languages for expressing properties of game strategies, checking whether a game strategy has winning or no-losing property reduces to the model checking problems. Secondly, logical formalisms are frequently more succinct, compared to the alternatives. Last but not least, logical representation and reasoning about game strategies might also be of value in game theory itself, as they open the door for automated reasoning tools such as theorem provers.

Let us briefly review the related work before introducing our plan. Genesereth *et al* [2] proposed a practical logical language to specify a game by the so-called *Game Description Language* (GDL). The language is much less expressive than other game logics, but rich enough for describing any finite combinatorial games. This language has been used as an official language for General Game Playing since 2005. Moreover, Zhang and Thielscher recently introduced a logical formalism based on GDL to represent game strategies [10]. With their framework, a strategy is represented as a logical formula. More importantly, strategies can be combined by using a pair of prioritised logical connectives. However, their work does not have the facility for reasoning about strategic abilities of players [11]. On the contrary, logics to reason about strategies are mostly based on either Pauly's Coalition Logic (CL) or Alur *et al*'s Alternating-time Temporal Logic (ATL) [1, 5]. Both logics use coalition modalities to specify strategic abilities of coalitions. These logics use existential quantifiers to express players' strategic abilities, such as '*a coalition of players has a strategy*

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*to achieve a game property*', while description of strategies is not part of the logical language.

Therefore, in our investigation, we would like to establish a logical framework that is capable of specifying game rules, representing game strategies as well as modeling strategic reasoning of players so that a computer may take up some active roles in strategic game playing. It is true that it is hard for a computer to automatically generate (discover) complicated and smart strategies for complicated games. However, with model-checking approaches, we expect that it is possible with our framework to verify if a strategy is a winning/no-losing strategy. With the current technologies, we believe that it is not impossible for a computer to create some simple strategies (or starting with human specified strategies, like heuristics) and try to combine them into more complicated ones to see whether they satisfy certain desired properties. To make this feasible, we refine this overall goal into three visible steps:

**Task 1:** Establish the syntax and semantics of the logical formalism. In order to establish a unified logical framework for representing and reasoning about strategies in game playing, the first step is to design a language which can (1) describe game rules specifying how to play a game; (2) reason about strategies in order to verify whether a given game is solved or has a winning strategy for some players; (3) represent and describe strategies explicitly so as to provide logical solutions for solved games. Meanwhile, we need to provide semantical models for interpreting the language as well as modelling real games.

**Task 2:** Design an algorithm for model checking problem of the proposed logic. To implement the proposed logic effectively and automatically, we will study its model checking problem. Particularly, we need to design an algorithm to automatically verify whether a given formula in our logic is satisfied by a given game structure. This technical result is significant, as it can be used to justify whether a game is determined and whether the logic is decidable.

**Task 3:** Investigate applications of the proposed logic. To demonstrate the applicability of our logic, we will apply it to the following three aspects. Firstly, with the help of model-checking approach, we may be also develop solutions for some unsolved games; Secondly, the proposed logic may be used to studying voting or aggregation in multi-agent environment. Moreover, it would be interesting to investigate the epistemic extension of the framework so as to study strategic reasoning in imperfect information games.

## 3. PROGRESS TO DATE

We have presented a unified logical framework for game description, strategy representation and strategic reasoning [3]. We call this logical framework GDR, standing for *a logic for Game Description and strategic Reasoning*. The language of GDR extends GDL with coalition operators from ATL and prioritised strategy connectives. Inherited from GDL, the proposed logical language can describe any finite perfect information game. Furthermore, by using Zhang and Thielscher's prioritised connectives and ATL-like coalition operators, the language can represent complicated game strategies and specify strategic abilities of players. More importantly, we provide unified semantics for both GDL- and ATL- formulas, which allows us to formalize the game-playing principles introduced by van Benthem [7]. These principles make it possible to formally derive two well-known results for two-player games: *Weak Determinacy* and *Zermelo's Theorem*. Meanwhile, we use a generalised Gomuko game to demonstrate how to use our logical formalism to describe a game strategy and reason about strategies. Currently we have presented an upper bound of the model-checking complexity of GDR.

Most recently, we have applied the intuition of prioritised strategy connective to social choice and proposed a simple yet expressive modal logic for modelling individual and collective choices over a set of feasible alternatives [4]. We call this logical framework R-CL, standing for *a logic for collective choice based on reasons*. The logic extends propositional logic with a prioritised connective so that a formula can express not only properties of alternatives but also priorities of individuals over the properties. More importantly, each formula of this logic determines a preference ordering over alternatives based on the priorities over properties that the formula expresses. In such a way, preferences of multiple agents can be represented by a set of formulas in the same logic. This allows us to treat the problem of collective choice in a multi-agent system as aggregation of logical formulas. We further use this language to express a few plausible collective choice rules. This enables us to employ the standard model checking techniques to generate individual and collective choices in this logic. Meanwhile, similar to preference aggregation, we specify a collective choice rule by Arrow's conditions. Interestingly, all Arrowian conditions are plausible under the new setting except Independence of Irrelevant Alternatives. This gives us a natural way to avoid Arrow's impossibility result.

There are two ongoing directions. By extending GDR with epistemic operators, we will represent and reasoning about strategies in imperfect information games. Meanwhile, we would like to apply the prioritised connective to belief merging.

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