Knowledge and games : theory and implementation

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Abstract

Does she know what he knows? And if so, what is she going to do?

This dissertation takes a computer science perspective on questions of knowledge and interaction and presents approaches for endowing artificial agents with corresponding reasoning capabilities.

To this end, we restrict general frameworks of epistemic logic and game theory in order to obtain practical implementations grounded in theory.

The basic idea of the main part of the dissertation (Chapters 1–3) is to view computer processes, or otherwise distributed programs, as players in a game-theoretic setting with incomplete information. As such, they should be able to communicate in order to obtain information, and to perform game-theoretic algorithms.

In Chapter 1, we establish the technical foundations to support implementation of synchronous communication, and thus the attainment of common knowledge, among computer processes representing players. To this end, we examine dialects of the process calculus CSP, which is available in the form of programming languages. We argue that for our purposes the process system needs to exhibit a certain symmetry, and show that to satisfy this requirement we need a certain guard construct in the language. Since this construct is not commonly provided, our result practically identifies a unique programming language suitable for our purposes.

In Chapter 2, we define what we call interaction structures, a concrete class of communication networks. We specify what kind of communication scenario we focus on, and study properties of the knowledge that results from such communication. These properties can be used to simplify reasoning about knowledge in our setting.

In Chapter 3, we study games in the presence of an interaction structure, which allows players to communicate their preferences, assuming that each player initially only knows his own preferences. We study the outcomes of iterated elimination of strictly dominated strategies that can be obtained in any given
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state of communication. The insights from the previous chapters are used in order to provide an epistemic basis for our results and to show a distributed algorithm that implements the procedures locally in each player process.

After this main part of the dissertation, we continue with more loosely related satellite chapters.

Chapter 4 is close to the main part in spirit, with the difference that it focuses on a centralized rather than a distributed approach, and that it considers computer games rather than games in the strict sense of game theory. We argue that reasoning about knowledge, including about each other’s knowledge, plays a crucial role in real-life strategic and social interaction. We survey existing literature and games which simulate such interaction, and show that this issue is currently neglected. We give concrete scenarios from existing computer games which could profit from incorporating such reasoning techniques, and substantiate one of them by describing a simple implementation intended for experimental evaluation.

In Chapter 5, we propose an abstract approach to coalition formation that focuses on simple merge and split rules transforming partitions of a group of players. We identify conditions under which every iteration of these rules yields a unique partition. The main conceptual tool is a specific notion of a stable partition. The results are parametrized by a preference relation between partitions of a group of players and naturally apply to coalitional TU-games, hedonic games and exchange economy games.

In Chapter 6, we extend the existing framework of mixed multi-unit combinatorial auctions to include time constraints, present an expressive bidding language, and show how to solve the winner determination problem for such auctions using an integer programming implementation. Mixed multi-unit combinatorial auctions are auctions where bidders can offer combinations of transformations of goods rather than just simple goods. For example, a transformation might take dough and water and yield bread. This model has great potential for applications in the context of supply chain formation, which is further enhanced by the integration of time constraints.

Finally, in Chapter 7 we give an outlook on possible future directions for implementing epistemic logic.