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INTRODUCTION TO THE SPECIAL ISSUE

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This special issue of the *International Game Theory Review* is on Logic and the Foundations of Game and Decision Theory. It contains a selection of papers presented at the 10*th Conference on Logic and the Foundations of Game and Decision Theory* (LOFT10), which took place at the University of Sevilla (Spain), July 18–20, 2012. On top of this, the issue contains an additional paper and a short note that fall within the theme of LOFT. While this special issue collects papers with a focus on game theory, a second set of papers that are more logic-oriented can be found in a special issue of the *Journal of Philosophical Logic* (Vol. 42, No. 6, 2013).

The LOFT conferences, which have taken place biannually since 1994, are interdisciplinary events that bring together researchers from a variety of fields: cognitive psychology, computer science and artificial intelligence, economics, game theory, linguistics, logic, philosophy and social choice. The central theme of the LOFT conferences has been the application of logic, in particular modal epistemic logic, to foundational issues in the theory of games and individual decision-making.[a]

Game theory provides a formal language for the representation of interactive situations, that is, situations where several "entities" — called players — take actions that affect each other. The nature of the players varies depending on the context in which the game theoretic language is invoked: in evolutionary biology players are nonthinking living organisms; in computer science players are artificial agents; in behavioral game theory players are "ordinary" human beings, etc. Traditionally, however, game theory has focused on interaction among intelligent, sophisticated and rational individuals. A relatively recent development in game theory, the so-called *epistemic foundation program*, has sought to characterize, for any game, the behavior of rational and intelligent players who know the structure of the game and the preferences of their opponents and who recognize each other's rationality and reasoning abilities. The two fundamental questions addressed in this literature are: (1) Under what circumstances can a player be said to be rational? and (2) What does "mutual recognition" of rationality mean? Since the two main ingredients of the notion of rationality are beliefs and choice and the natural interpretation of "mutual recognition" of rationality is in terms of common belief, it is clear that the tools of epistemic logic are the appropriate tools for this program. The expression "interactive epistemology" has been used in the game-theory literature to refer to the analysis of strategic interaction based on an explicit modeling of the players' beliefs about each other's beliefs and rationality.[b]

The LOFT conferences arose from the realization that the tools and methodology that were used in game theory were closely related to those used in other fields, notably computer science, logic and philosophy. Modal logic turned out to be the common language that made it possible to bring together different professional communities. It became apparent that the insights gained and the methodologies employed in one field could benefit researchers in other fields. Indeed, new and active areas of research have sprung from the interdisciplinary exposure provided by the LOFT events. Over time the scope of the LOFT conferences has broadened to encompass a wider range of topics, while maintaining its focus on the general issue of rationality and agency. Topics that have fallen within the LOFT umbrella

[a]The first conference was hosted by the Centre International de Rencontres Mathématiques in Marseille (France), the next four took place at the International Centre for Economic Research in Torino (Italy), the sixth was hosted by the Graduate School of Management in Leipzig (Germany), the seventh took place at the University of Liverpool (United Kingdom), the eighth at the University of Amsterdam (The Netherlands) and the ninth at the University of Toulouse (France).

[b]The definition of a game, whether it is in strategic-form or extensive-form, provides only a partial description of an interactive situation, since it does not specify what choices the players make, nor what beliefs they have about their opponents' choices. A specification of these missing elements is obtained by introducing the notion of an epistemic model of a game, which represents a possible context in which the game is played.

include epistemic and temporal logic, theories of information processing and belief revision, counterfactual reasoning, models of bounded rationality, nonmonotonic reasoning, theories of learning and evolution, social choice theory, etc. This special issue contains papers that have a clear focus on game theory and at the same time reflect the general interests and interdisciplinary scope of the LOFT community.[c]

The paper "From classical to epistemic game theory" by Andrés Perea provides a detailed historical account of the development of the epistemic foundation program in game theory. The author starts by noting that, despite the fact that Oskar Morgenstern had argued for the need to develop models that explicitly deal with the reasoning of the players about the choices and beliefs of their opponents, the initial approach to game theory — what Perea calls the "classical" approach — ignored these issues for several decades. It was not until the 1960s that the epistemic approach started taking roots. After a careful account of the first relevant contributions, Perea outlines the two types of epistemic models of strategic-form games used in the literature: the "state-space" models, that are essentially the Kripke models studied in philosophy and modal logic (introduced by Saul Kripke in 1963), and the "hierarchy of beliefs" models, that have their origin in the seminal papers of John Harsanyi on incomplete-information games. In game theory the state-space approach is mainly associated with the contributions of Robert Aumann. Perea identifies the concept of *common belief in rationality* as the central idea in epistemic game theory and gives a detailed account of the gradual development of this notion.

The purpose of Michael Trost's paper "An epistemic rationale for order independence" is to provide an epistemic justification for the application of order-independent iterative deletion procedures to strategic-form games. Iterative deletion procedures are often used to solve games. The first step consists in defining what an "inferior" strategy is and then one proceeds by deleting inferior strategies, thereby obtaining a smaller game; the procedure is then repeated in the smaller game to

[c]Collections of papers from previous LOFT conferences can be found in a special issue of *Theory and Decision* (Vol. 37, 1994, edited by M. Bacharach and P. Mongin), the volume *Epistemic logic and the theory of games and decisions* (edited by M. Bacharach, L.-A. Gérard-Varet, P. Mongin and H. Shin, Kluwer Academic, 1997), two special issues of *Mathematical Social Sciences* (Vols. 36 and 38, 1998, edited by G. Bonanno, M. Kaneko and P. Mongin), two special issues of the *Bulletin of Economic Research* (Vol. 53, 2001 and Vol. 54, 2002, edited by G. Bonanno and W. van der Hoek), a special issue of *Research in Economics*, (Vol. 57, 2003, edited by G. Bonanno and W. van der Hoek), a special issue of *Knowledge*, *Rationality and Action* (part of *Synthese*, Vol. 147, 2005, edited by G. Bonanno), the volume *Logic and the Foundations of Game and Decision Theory* (*LOFT* 7) (Vol. 3 of *Texts in Logic and Games*, edited by G. Bonanno, W. van der Hoek and M. Wooldridge, Amsterdam University Press, 2008), the volume *Logic and the Foundations of Game and Decision Theory* — (*LOFT* 8) (Vol. 6006 of *Lecture Notes in Artificial Intelligence*, edited by G. Bonanno, W. van der Hoek and B. Löwe, Springer, 2010), a special double issue of the *Journal of Applied Nonclassical Logics* on "Logical aspects of game theory (LOFT 2010)", edited by G. Bonanno, A. Herzig, J. Lang and W. van der Hoek (Volume 21, Numbers 3–4, 2011) and in a special issue of the *International Journal of Game Theory* (Vol. 42 No. 3, 2013) edited by G. Bonanno, A. Herzig, J. Lang and W. van der Hoek.

yield an even smaller game, and so on, until no further deletions are possible. It is well-known that some iterative deletion procedures enjoy the property that the final output is the same, irrespective of the order in which the deletions are performed. Such procedures are called *order independent*. An example of an order-independent procedure is the iterative deletion of strictly dominated strategies. On the other hand, there are iterative deletion procedures where different orders of deletions lead to different final outputs. An example is the iterative deletion of weakly dominated strategies. Consider the output obtained by applying some iterated maximal deletion procedure ("maximal" means that all inferior strategies are simultaneously deleted in each round) and compare it to the set of strategy profiles that are possible if all the players apply the choice rule on which the deletion procedure is based and, furthermore, this fact is commonly believed by all players. If the two sets coincide, Trost calls the deletion procedure under consideration *justifiable by the common belief of choice rule following behavior*. Trost provides an answer to the following question: for what class of choice rules is the order independence of an iterative deletion procedure based on such rules equivalent to its epistemic justification by the common belief of choice rule following behavior?

The paper "Universally rational belief hierarchies" by Elias Tsakas falls within the hierarchy-of-beliefs approach to epistemic game theory. When a player reasons about her opponents in a game, she not only holds beliefs about what the other players will do (first-order beliefs), but also second-order beliefs about the opponents' first-order beliefs (about what others do) and third-order beliefs about the opponents' second-order beliefs, and so on. Thus each player holds an *infinite belief hierarchy*. Such belief hierarchies are very complex objects, but Harsanyi proposed an indirect way of representing belief hierarchies through the notion of type. A type of a player consists of a choice of strategy for that player, together with a probability distribution over the cartesian product of the strategy profiles of the other players and the profiles of types of the other players. In an earlier paper Tsakas restricted attention to probabilistic beliefs that can take on only rational values (thus ruling out, for example, a belief that attaches probability $1/\sqrt{2}$ to an event E). He called such beliefs "rational beliefs" and showed that the universal rational type space exists. However, he also showed that there exist some rational types which are associated with nonrational probabilities, even though every order of belief hierarchy involves only rational probabilities. In the paper contained in this issue Tsakas identifies and characterizes the rational types that do not exhibit this property, that is, provides conditions on the belief hierarchies that are necessary and sufficient for the associated probability measure over the product of the underlying space of uncertainty and the opponents rational types to assign rational probabilities to all Borel events. He calls these types *universally rational*.

The paper "A general notion of uniform strategies" by Bastien Maubert and Sophie Pinchinat provides a detailed account of various uniformity issues for in principle infinite arenas. In an imperfect information game, a rational player cannot choose between strategies that are indistinguishable from her perspective. She should choose between *uniform strategies* that apply in the player's entire equivalence class. The authors present generalizations (such as the infinite arenas) of this imperfect information setting, including synthesis of uniform strategies for the restriction to finite arenas. In somewhat more detail, they consider two-player turn-based game arenas. Uniformity properties involve sets of plays in order to express constraints on strategies that are not μ-calculus definable. Typically, one can represent constraints on allowed strategies, such as observation-based strategies. The formal language to specify uniformity properties involves a modality called R, meaning "for all related plays". Its semantics is given by a binary relation between plays. The authors also investigate an automated procedure to synthesize strategies subject to a uniformity property. This extends existing results based on temporal logics. They give a generic solution for the synthesis problem, provided that the binary relation that defines the sets of related plays is recognizable by a finite state transducer. This solution yields a procedure of nonelementary complexity.

The paper "Backward Induction or Forward Reasoning? — An Experiment of Stochastic Alternating Offer Bargaining" by Siegfried Berninghaus, Werner Güth, and Stephan Schosser reports on an experimental study of a stochastic, alternating offer game under incomplete information. There is a certain first-period pie and a known and finite deadline. The players know neither the continuation probabilities nor the sizes of future pies. They can, however, obtain this information at a cost. The paper analyzes game behavior and acquisition of information, with the purpose of classifying players in groups such as "backward induction", "equal split", "expectations-based forward reasoning" and "socially acceptable forward reasoning". The information acquisition part of the game is innovative, but it also gives rise to a game of high complexity.

The paper by Miklós Pinter, "On the Completeness of the Universal Knowledge-Belief Space: a Technical Note", takes as its starting point the 1967–1968 papers by John Harsányi on incomplete information games. Harsányi suggested to substitute types for belief hierarchies, collect all types in an object, and then consider probability measures on the object as the beliefs of players. This object into which all types are collected is called the universal type space. Martin Meier showed in 2012 that this space is complete. Now, type spaces can be extended to represent not only beliefs, but also the knowledge of players. This construction is known as the knowledge-belief space. Pinter introduces the notion of a complete knowledge-belief space and demonstrates that the universal knowledge-belief space is not complete.

The guest editors of this special issue would like to thank the authors for their submissions, the LOFT participants for their lively discussions and the many reviewers for their invaluable help during the thorough reviewing and editorial process. Last but not least, our thanks go to the Editors of the *International Game Theory Review*, for making this special issue possible.