Motivation

The goal of my thesis work is to develop game analysis techniques capable of informing strategy design in large, complex games. Broadly defined, games are situations where multiple players make interacting decisions; each players’ choice depends on the choices of the other players. The formal study of games has origins in economics, but in recent years game theory has drawn increasing interest in computer science. Computer science offers a rich set of tools for advancing the art of game analysis, including simulation methods that can be used to explore strategic interactions in games.

Game theory has achieved significant success and popularity, but practitioners have had mixed success applying the theory to real strategy design problems (Roth 2002). An acute challenge in game theory applications is the size and complexity of real games, which often require players to choose among very large sets of distinct courses of action. A second (related) challenge is that players and analysts typically face substantial uncertainty about the outcomes due to computational and observational limitations. Large games exacerbate these uncertainties to the extent that they arise from resource limitations. This form of uncertainty is particularly difficult to characterize due to the intricacies of gathering evidence about game outcomes.

Consider, for example, the Trading Agent Competition Supply Chain Management game (TAC SCM) (Arunachalam & Sadeh 2005; Kiekintveld et al. 2006). This is a game of significant interest among researchers, and game-theoretic investigation of this game forms part of my thesis. The game is an hour-long simulation of a supply chain scenario played by automated agents. The space of possible agent designs is extremely large and – despite countless hours of investigation – no optimal solution is known or on the horizon. Like many real games of interest, TAC SCM is defined in a compact form, by a set of game rules and game server that implements those rules.1 We can gather evidence about the SCM game by simulating game instances, but even using thousands of hours of simulation time we are only able to sample a small fraction of the full TAC SCM strategy space.

Complex games like TAC SCM are not easily reduced to explicit, tractable game models of the form common in the game theory literature, and they often defy exact analytic solution using conventional tools. I believe that the insights of game theory can still be a valuable guide to developing strategies in complex domains. However, there is a pressing need for solution techniques based on game-theoretic principles that can meet the challenges of these complex domains.

Research Overview

I adopt the framework of empirical game theory, an emerging methodology for principled analysis of large games. This methodology makes explicit the process of exploring and modeling the game as part of the analysis. The typical approach is to use simulation to derive an empirical estimate of the game form, which may be noisy and incomplete. Various game-theoretic solution concepts can be applied to the empirical game, including equilibrium models. The outcome of this analysis may be used to drive further simulation and experimentation.

My thesis contributes to the growing body of evidence that empirical game-theoretic analysis can yield useful strategic guidance in very complex domains. I apply these techniques to analyses of the TAC SCM game (Wellman et al. 2005a; Vorobeychik, Kiekintveld, & Wellman 2006; Jordan, Kiekintveld, & Wellman 2007) and a four player variant of chess called chaturanga (Kiekintveld, Wellman, & Singh 2006). As an example, the study in (Vorobeychik, Kiekintveld, & Wellman 2006) provides strong evidence that a rule change in the SCM game intended to curb undesirable early purchasing behavior by the agents had little chance to have the desired effect, based on rational agent responses. Other examples of successful applications of empirical game theory from the literature include continuous double auctions (Phelps et al. 2005) and simultaneous ascending auctions (Reeves et al. 2005).

The preceding studies propose a wide variety of candidate algorithms for analyzing games, and further examples can be found in the literature. To date, there is very little evidence to support comparison of the candidate approaches to determine which yield the best results under varying conditions. The remainder of my thesis develops an experimental
framework for evaluating candidate algorithms, and applies this framework to test specific hypotheses about the relative performance of candidates on different classes of games.

I propose evaluating candidate algorithms by analyzing meta-strategy games. Each candidate is a meta-strategy: a high-level strategy that selects a specific strategy to play given (limited) observations of any game instance drawn from some class of games. Since the performance of the selected strategy depends on the context of strategies chosen by the opponents, we must specify how the opponents select strategies. If we assume that the opponents are also using one of the candidate meta-strategies, this induces a game between the candidates that I refer to as the meta-strategy game. This game can be analyzed using common solution concepts including dominance and Nash equilibria. Intuitively, we are interested in the possibility that a player analyzing the game in one way would have an incentive to switch to an alternative method of analysis. This approach is similar in spirit to evaluations of single-agent learning methods. A key distinction is that this approach accounts for the possibility of strategic interactions between meta-strategies by considering them to be participants in a game.2

I use apply this framework to explore two issues of interest. The first is motivated by the uncertainty present in empirical estimates of games due to sampling noise and incomplete data. In principle, solutions concepts applied to these estimates should yield better and more robust answers if they account for this uncertainty in some way. However, the exact distribution of noise is unknown. Nevertheless, some methods that incorporate models of noise (such as $\epsilon$-Nash or quantal-response equilibrium (McKelvey & Palfrey 1995)) may serve as good heuristic approximations under many conditions. I hypothesize that solution concepts that yield broader, distribution-based predictions of the outcome will be more robust to the presence of significant noise than point-based solutions.

My second experiment is motivated by the observation that many real games seem to exhibit high degrees of structure that could be exploited to more efficiently explore these games. I test the ability of several candidates to exploit unknown independence structure in games to direct sampling towards the most relevant regions of the outcome space. I hypothesize that adaptive learning methods are one class of methods that is able to efficiently exploit independence structure, including noisy variations. A second class of candidates that should demonstrate strong performance on this class of games are variants of the best-first search for equilibria first proposed in (Wellman et al. 2005b).

References


2Tournaments and factorial analysis are two alternative evaluation criteria that appear in related literature; each is less comprehensive than the full game-theoretic analysis.