The Role of Anticipation on Cooperation and Coordination in Simulated Prisoner's Dilemma Game Playing

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Abstract. We present a connectionist model for the Iterated Prisoner's Dilemma game. The model was validated by comparisons with human subjects' experiments in which subjects played individually against a computer opponent. After reproducing several interesting characteristics of individual play, we used the model in multi-agent simulations of small societies in which agents interacted among each-other by playing the Iterated Prisoner's Dilemma game. The role of anticipation on cooperation and coordination was our main interest. The findings are that anticipation is decisive for high level of cooperation and higher cooperative coordination in our simulated societies.

1 Introduction

In standard game theory, players are described as perfectly rational and possessing all the information present in the game including knowledge about the possible moves and payoffs, and opponents. On the other hand, the bounded rationality view on cognition states that people are almost never perfectly rational (Colman, 2003) due to limitations in perception, time, thinking, and memory.

Our main interest is in the social behavior of computational models whose performance can be compared against data from human participants. In the anticipation model proposed by Lalev and Grinberg (2007), the role of anticipation on cooperation in the Iterated Prisoner's Dilemma game (IPDG) was investigated. The detailed analysis of the model features demonstrated the importance of prediction for adequate description of the behavioral data on cooperation.

The model player was also applied in Multi-Agent Simulations (MAS) of small societies meant to represent effects within groups of IPDG players. The results of these simulations demonstrate the role of anticipation on cooperation and coordination as related to the essence of social interaction.

1.1 The Prisoner's Dilemma Game

The Prisoners Dilemma game is intriguing for it contains an analogue of the problem of cooperation in everyday life. This is a two-person game. The players simultaneously choose their move - cooperate (C) or defect (D), without knowing their opponent's choice.

R is the payoff if both players cooperate (play C), P is the payoff if both players defect (play D), T is the payoff if one defects and the other cooperates, S is the payoff if one cooperates and the other defects. The payoffs satisfy the inequalities T > R > P > S and 2R > T + S.

The quantity cooperation index (CI) (CI = (R-P)/(T-S)) is a predictor of the probability of C choices, monotonously increasing with CI (Rapoport and Chammah, 1965). Players are thought to pay attention to CI, and thus, to the game payoff structure.

In IPDG, sophisticated relations, including theory of mind and reputation formation, emerge (see Taiji and Ikegami (1999), Camerer et al. (2002)). They are related to anticipation in decision making (Rosen, 1985). This behavior sometimes gives rise to cooperative strategies like in Taiji and Ikegami (1999) and Lalev and Grinberg (2007).

2 Description of a connectionist IPDG model

Our IPDG model architecture is based on a recurrent Elman neural network (Elman, 1990) from Figure 1. A forward-looking evaluation mechanism realizes anticipatory decision making. In IPDG, the network processes the flow of available information - CI, players' moves and payoffs obtained from the game. Due to its learning, the network is able to correlate this information over time, and tries to infer information which is not available yet. Such information is for example the strategy of the opponent.

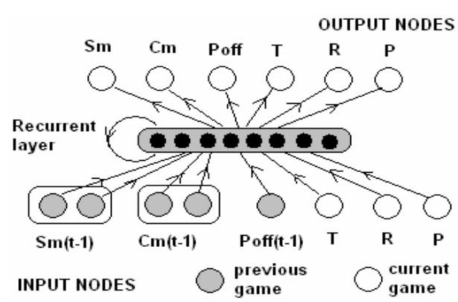

Fig. 1. Schematic view of the recurrent neural network and its inputs and outputs/targets. Notation: Sm and Cm are respectively the simulated subject and computer opponent (probability for) moves; Poff(t) is the model's received payoff at time t.

The prediction for the move of the opponent is used in the forward-looking mechanism to perform anticipatory decision-making. The model explores how the game would proceed in case it palyed cooperatively or non-cooperatively in the present game. The predicted strategy of the opponent is used to calculate payoffs from the fictitious play of the model. Then the gains in terms the of sums of fictiitous game payoffs are evaluated for both alternative choices. The move leading to a higher predicted gain is predominantly chosen. Thus, decision making is achieved with the help of anticipation of the opponent's move and the future payoff.

In this form, the model managed to reproduce results from experiments with human subjects by Hristova and Grinberg (2004). These results regard the CI influence on cooperation, mean cooperation values, number of game outcomes, and payoffs. Exploration of anticipation forward-looking parameters revealed that the anticipatory properties of the model's decision making are maybe the only explanation of the emergence of CI-influenced cooperation (Lalev and Grinberg, 2007).

3 Multi-Agent Simulations

Here, we present the results from simulations of the interactions in a society of artificial players implementing such a model. The aim of the simulations was to investigate the role of anticipation on cooperation and coordination in a society of payoff-maximizing agents.

With instances of the validated model architecture, simulations of IPDG playing in small societies were conducted. The aim of the simulations was to investigate the role of anticipation in a society of payoff-maximizing agents on cooperation and coordination among them. For this purpose, groups of 10 agents with different parameterization of the model played IPDG in simulated social environments. Regarding parametrization, there were 5 types of players: The first type had very restricted anticipatory abilities and it mattered only the present PD game. Each next player type used higher predefined anticipation than the previous ones. The fifth player type played 10 fictitious games with predicted game information before making its decision to cooperate or not. There were multiple 100-game long sessions between randomly assigned couples of players in each society.

To analyze the processes in each society, the overall level of cooperation, mean paypoffs, as well as cooperative coordination were investigated. It turned out that the level of cooperation in the simulated IPDG societies grew with anticipation starting from 5 percent in the first society and reaching up to 34 percent in the fifth society. Corresponding to their anticipation, the intermediate types reached intermediate levels of cooperative interactions (Figure 2). A tendency of increase of the mean number of mutual coperation cases per simulation was observed with increase of the anticipatory properties of agents in the societies. The opposite was valid for the mean number of double non-cooperative choices (mutual defection) per simulation as this number increased with diminishing of anticipation in the societies.

The summary payoffs that were gained after the end of simulations in each society were also positively correlated with forward-looking abilities: the higher

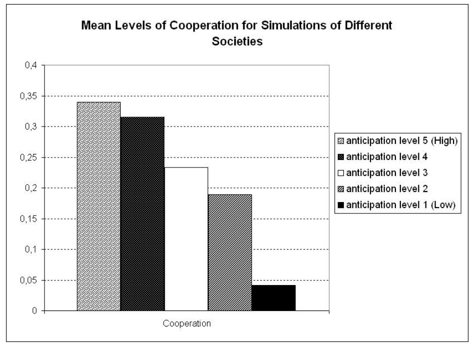

Fig. 2. Mean level of cooperation in simulations.

the anticipation within a society was, the higher the payoffs were obtained by the members of the corresponding society.

A measure of the level of coordination between the agents we used was the mean number of mutual cooperation games played consequtively per IPDG session. The longest mutual cooperative coordination lasted for five games and was present only in 2 of the societies with highest anticipation. Four-games-long sequences were observed also in the latter and in the third societies. In the first, low-anticipation society, no sequences longer than two were found. Although the sequences are not very long, the influence of anticipation is considerable. Additionally, only 70 percent of the agents from the low-anticipation society ever played a mutual cooperation game whereas for all other societies this percentage equals 100.

4 Conclusion

These simulations clearly showed that anticipation is decisive for high level of cooperation and higher coordination. According to the results, the higher the anticipatory ability is, the higher the cooperation rate and the coordination in cooperation between agents are. As human cooperation in IPDG is close in rates to the cooperation of our anticipatory agents, the prediction is that coordination series among human subjects may be in close ranges to those, observed in the simulations.

For the parametrization of the agents in the simulated societies was predefined here, the question arose whether anticipatory properties will also appear in societies of evolving agents. According to some preliminary results, anticipatory agents are the ones with the best evolutionary fitness in cooperative societies.

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