DESIGN OF COLLECTIVE BEHAVIOR
IN MULTI-AGENT SYSTEMS

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I. Introduction

The problem of designing a given social behavior (e.g. cooperation, compromise, negotiation, altruism) in Multi-Agent Systems (MAS) is a well known issue, still there is no general approach to solve it. In fact, there is no general and comprehensive theory connecting the individual behavior of agents with the collective behavior of the MAS. Nonetheless there are theories, which capture some profound aspects of the problem (e.g. game theory [1], theory of implementation of social choice rules [2], satisficing games [3]). Inspired by these theories a high-level model of agent decision mechanism, called virtual games, was developed [4]. The new concept overcomes most of the weaknesses of its predecessors, and provides a tractable solution to the problem.

II. The new approach

MAS are usually considered from the perspective of intelligent agents. An *agent* "can be anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors." [5]. Now, the high-level agent-model proposed [4] is the following (see. Fig. 1).
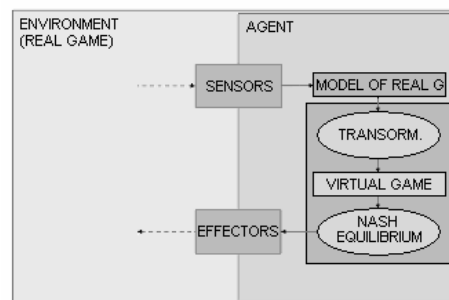

Figure 1: The new approach to the implementation problem

In multi-agent environments agents must consider the activity of other agents for effective operation. Such situations of strategic interaction are commonly modeled by game theory. Thus, the MAS environment is seen, as if it was a Bayesian game [6], where agents are *players*; the possible architectures for running agent-programs are the possible *types* of the players; agents' beliefs correspond to probability distributions over the types of the players; agents' programs correspond to *strategy profiles* of the players; and agents' plans are *strategies* of the players. Strategy profiles associate strategies to the types of the players.

Now, the lifecycle of an agent is the following: (1) first it senses the environment, i.e. the *real game*. (2) From that percept it creates a representation of the environment, i.e. the *model of the real game*. (3) This Bayesian game is the input of its *decision mechanism* choosing among possible plans, i.e. strategies. Finally, (4) the agent acts according to the strategy recommended by its decision mechanism, and then continues at step (1).

The decision mechanism of the agent has three parts: a *transformation*, a *virtual game*, and a *function for selecting a Nash-equilibrium* [6]. The transformation is responsible for generating the virtual game from the model of the real game. It may use any aspect of the model of the real game

(e.g. strategies, types, utilities). Thus the virtual game has strategies, called *virtual strategies*, and utilities, called *virtual utilities*, which may be different from those found in the model of the real game, because this way the incentives, private valuation and preferences over the possible outcomes of every single agent can be represented, and agents' individual rationality is connected with the rationality of the collective. While the concept of real utility is inherently selfish, virtual utility may reflect not only an agent's own interest, but the interest of others as well. Thus, a virtual game is "virtual" in a sense, that it isn't intended to describe or model the real game. It is only intended to "guide" the decision making of the agent in a sense, that the third component of the decision mechanism (which is responsible for selecting the strategy played by the agent), the function for selecting a Bayesian Nash-equilibrium is based upon it. Nash equilibrium is an inherently non-cooperative concept for maximizing expected profit, but since cooperative aspects are incorporated into the virtual utilities, it is appropriate. Thus the decision mechanism is eventually controlled by the virtual game, mainly by the virtual utilities. Lately it was shown, that – even with binary virtual utilities – any collective behavior in a MAS can be implemented exactly.

III. Comparison with some common approaches

Theory of games [1] provides an elaborate description framework, but does not specify how the agents' decision mechanism works. This makes game theory inappropriate for the design of collective behavior in MAS, where agents should act according to a specified rule of behavior. A new branch in game theory, *theory of implementation of social choice rules* [2] tries to implement a given collective behavior by constructing a *mechanism* centered above the agents, which produces the necessary outcomes by interacting with the collective. It considers agents to be given, and therefore specifies the decision mechanism not inside, but outside of them. This causes some fundamental difficulties (e.g. generally only approximate implementation is possible), which may be overcome, if the mechanism is distributed among the agents, like in the new approach. *Theory of satisficing games* [3] is one of the latest approaches to address the problem. It has essentially the same potential as the new approach [4], but it is more complex and the preferences of agents are represented with orderings, not utilities. The lack to represent cardinal relationships (e.g. degree of superiority) between the goodness of different outcomes is also a weakness.

IV. Conclusion

The article presented a novel method to describe, design, and analyze collective behavior in MAS. The goal was to develop a general method that overcomes the weaknesses of the previous approaches. It was shown, that arbitrary collective behavior can be implemented exactly and in general, which is a significant step in the theory of implementation. Nevertheless, the design principles enabling the construction of MAS operating according to a given social behavior are still under development. Thus, future research will mainly concentrate on synthesis: connecting the concept with existing low-level agent architectures and making practical MAS design possible.

References

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