

Coalition Formation Strategies for Self-Interested Agents in Hedonic Games

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Abstract. In this article, we address the problem of coalition formation in multiagent systems. Our work focuses on the class of hedonic games, where the satisfaction of each agent depends on other agents taking part in the coalition. We present in this paper some strategies, which could be used by agents. We describe two types of strategies: *proposal acceptance strategies*, which allow agents to accept or reject a coalition formation proposal and *proposal selection strategies* based on the analysis of the history of a negotiation, which allow agents to select interesting coalitions to propose. We underline that a compromise between high and low selectivity allows agents to obtain a higher probability to form coalitions with a satisfying utility. Our *proposal selection strategies* allow agents to reduce the number of proposals to send during the coalition formation process without losing much utility. This speeds up considerably the process.

1 INTRODUCTION

In a multiagent system, agents are usually guided by specific objectives they intend to reach. They behave autonomously and are able to communicate directly with each other. In the context of hedonic games, agents are self-interested and their objective is to form coalitions with other agents. When an agent forms a coalition its level of satisfaction depends on other members of the coalition. Since agents are self-interested, their objective is to form the coalition, which has the highest possible rank in their own preference order.

Hedonic games have previously been studied in Economics [3]. Economic models focus on the analysis of hedonic games using different solution concepts. These models do not consider agents as able to behave autonomously like in multiagent systems.

In multiagent domain, some works propose algorithms for coalition formation but none of them deals with the problem of designing agent strategies in a hedonic game.

Some works on coalition formation deal with self-interested agents [4, 5, 1]. However, the context of these works is far from hedonic games and their strategies cannot be adapted to our context.

2 PROBLEM DESCRIPTION

We consider a set of n agents $N = \{a_1, \dots, a_n\}$. A coalition c is a nonempty subset of N . We define $\mathcal{C}$ as the set of all coalitions and $\mathcal{C}_i$ the set of coalitions containing agent a_i . When a coalition c is formed, each agent a_i in c gets a satisfaction defined by a utility function u_i on the set $\mathcal{C}_i$. This function induces a preference order $\succsim_i$ on coalitions of $\mathcal{C}_i$. A hedonic game H is a set of agents N and a

preference order $\succsim_i$ for each agent $a_i \in N$. A solution of a hedonic game is a coalition structure π : a partition of N .

In a multiagent system, agents have to coordinate themselves and form coalitions through direct negotiation without any external decision-maker or central truthful algorithm. Each agent makes its own decisions locally during the negotiation phase. Each agent has different preferences regarding the coalitions and does not have to reveal them explicitly; thus, it is unaware of the preferences of other agents. To do that, agents exchange messages about the coalitions they want to form. A coalition is formed when all participating agents approve it. This common agreement acts like a contract among its members.

In addition, agents need a common protocol, which they must follow and private behavior strategies to make decisions on the actions they undertake during this process. In a hedonic game, agents need to find partners interested in forming coalitions. They also need strategies to choose partners and strategies to answer to the requests of other agents.

Therefore, the study of a hedonic game in a multiagent context comes to the study of a coordination protocol and some behavior strategies. The protocol encompasses all the allowed interactions and the strategies are followed by agents in order to get a high utility i.e. to form a coalition, which is as high as possible in their preference order.

3 MODEL DESCRIPTION

3.1 Proposal Acceptance Strategy

When an agent a_i receives a proposal of coalition c at a time t , it can either accept it or refuse it. If the utility $u_i(c)$ is high enough, it accepts it, but if $u_i(c)$ is too low, a_i refuses it. We propose to define a threshold $s_i(t)$ such as (1) if $u_i(c) \geq s_i(t)$ then a_i decides to take part in the coalition (acceptance) and (2) if $u_i(c) < s_i(t)$ then a_i refuses to take part in the coalition (withdrawal). The domain of the function $s_i(t)$ is bounded by u_i^{alone} , the utility of the coalition singleton $\{a_i\}$ which is guaranteed (lower bound) and $u_i^{min}(t)$ the minimal utility of all coalitions already proposed by agent a_i at time t (upper bound).

We choose to define $s_i(t)$ as a decreasing function so that the agent a_i becomes less and less selective during the negotiation if it does not succeed in forming a coalition. The function is parameterized by a variable $\alpha_i \in [0, 1]$: $s_i(t) = u_i^{alone} + \alpha_i (u_i^{min}(t) - u_i^{alone})$. Parameter α_i is predetermined by the agent or its designer and reflects its selectivity: the more α_i close to 1, the more the agent is selective.

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3.2 Proposal Selection Strategy

Each agent has a proposal strategy that enables it to select which coalition to propose at a time t in the negotiation.

Preference Order-Based Proposal Selection Strategy A simple strategy consists of sending proposals sequentially, respecting the preference order over coalitions. This strategy may require many proposals before succeeding in finding an interesting coalition.

In some situations or real applications, we claim that agents do not always need to obtain the highest possible utility. Some agents can get satisfaction from a lower utility if in return they get satisfaction from another criterion, such as time minimization. We propose two history-based *proposal selection strategies* in order to reduce the number of proposals and to select only the interesting ones, while trying to minimize the loss of utility. We propose two strategies, based on the same principle: an agent a_i evaluates each coalition following its preference order and proposes a coalition only if it estimates that the coalition is worthwhile.

We summarize the process in the following algorithm, where c_j is the coalition of rank j in the preference order of a_i , $\delta(c)$ is an evaluation function in $[-1, 1]$ indicating whether it seems interesting for a_i to propose c : the lower the $\delta(c)$ is, the more c is interesting, and d_i is a threshold predetermined by the agent or its designer, which has an influence on the number of coalitions that will be selected to be sent or not. Then we describe in the following section two evaluation functions $\delta(c)$, measuring the degree of interest of a coalition c .

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j ← 0
do
  if  $\delta(c_j) \leq d_i$  then  $a_i$  proposes  $c_j$ 
  else j ← j + 1
until  $a_i$  has formed a coalition OR  $c_j = \{a_i\}$ 

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History-Based Proposal Selection Strategies During the coalition formation process, each agent a_i receives some proposals from certain agents and sends proposals to others. An agent a_i can assume that proposals it receives are well valued by their sender agent. Moreover, it knows which agents are interested in its own proposals. Assuming that preferences of other agents are structured (i.e. are not completely random), an agent a_i can use the history of all negotiations as a source of information that can be used in order to improve its future proposals.

Nearest Previous Proposals (NPP) Selection Strategy: Agent a_i stores all the proposals it has received and sent as well as the responses of the solicited agents. The main idea of this strategy is that if c is similar to a coalition c_1 already sent by a_j or similar to a coalition c_2 previously proposed by a_i to a_j , which was accepted by a_j , then since c_1 or c_2 were previously interesting for a_j , c is supposedly interesting for a_j too. To compare c to the previous proposals, a_i uses the following normalized distance measure: $d(c_1, c_2) = \frac{1}{n} |(c_1 \cup c_2) \setminus (c_1 \cap c_2)|$

For each solicited agent a_j in c , a_i computes: the distance between c and (1) all the proposals received from a_j and stores the minimum $d_i^{rcv}(c)$; (2) all the proposals sent to a_j , which have been accepted (resp. refused) by a_j and stores the minimum $d_i^{acc}(c)$ (resp $d_i^{ref}(c)$). Then a_i computes for each solicited agent a_j , the degree of interest $\delta_j(c) = \min(d_j^{rcv}(c), d_j^{acc}(c)) - d_j^{ref}(c)$. The coalition c can be formed if *all* the solicited agents are interested. Then to measure the potential of a coalition c , a_i analyses the degree of the most reluctant solicited agent, which has the highest $\delta_j(c)$: $\delta(c) = \max_{a_j \in c} \delta_j(c)$.

Frequency-Based (FB) Selection Strategy: As the *NPP strategy* needs to store all the proposals, which may be costly in memory, we propose a second algorithm, which uses only the frequency of the

presence of other agents in the previous proposals. The main idea of this strategy is that if agents in c are frequently present in proposals received from an agent a_j or accepted by a_j , we expect that c is potentially interesting for a_j . To do so, agent a_i computes d_j^{rcv} (resp. d_j^{acc} and d_j^{ref}) using a normalized Manhattan distance between c and the vector of occurrence of tasks in proposals received from a_i (resp. accepted and refused).

4 EXPERIMENTAL STUDY

We have performed experiments on a system with 15 agents.

Proposal Acceptance Strategy First, we analyze the influence of the parameter α_i of $s_i(t)$ when the agents implement the *preference order-based selection strategy* and have random preferences. We observe that selective agents get a better utility as solicited agents but the probability of finding an interesting coalition is low. Unselective agents increase their chance to find an interesting coalition but with a lower utility. When implementing risk-averse agents, we advise to set a mid-range value to α_i (about 0.5). It allows the agents to get the same utility on average when leaving the system either with a solicited role or an initiator role.

Proposal Selection Strategy We have tested our algorithms with agents with utility functions, which have a GAI (general additive independence)-decomposable structure [2]. We varied the threshold d_i of our two history-based proposal selection strategies. With a value of d_i close to 0, agents send few proposals. For values of d_i greater than 0.5, almost all proposals are sent. We have compared both strategies with a probabilistic strategy, which consists for an agent of proposing coalitions following its preference order, but with a prefixed probability p_i .

With the probabilistic strategy, the number of agents which leave the system in the singleton coalition increases when the agents have sent only few proposals. Conversely the number of initiators and solicited agents decreases. This leads to the decrease in the utility.

Contrary to what we observe with the probabilistic strategy, both history-based strategies allow agents to select only worthwhile proposals. The number of agents of each type is stable and decreases only slightly when the number of sent proposals is very low and we do not observe the decrease in the utility when the number of proposals decreases.

In both experiments, the *NPP strategy* is quite better than the *FB strategy*, however this algorithm has some drawbacks: it needs to store all the proposals and needs to compute all the distances. *FB strategy* only needs to store the frequencies and the computation of frequency vectors and the Manhattan distance is very fast.

We can conclude that the strategies we proposed allow the agents to select only useful proposals and to avoid sending proposals, which are potentially uninteresting for at least one agent in the set of solicited agents. This allows agents to send fewer proposals i.e. to save time during the coalition formation phase and preserve their utility.

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