Social Interaction under Uncertainty in Multi Agent Systems

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Introduction

Multi-agent systems deal with environments comprising several agents that interact with each other. The development of distributed, interconnected computer systems has invoked the rapid growth of this research area. Such settings, where one software agent interacts with another, require studying interactions such as coordination, cooperation and negotiation. In fact, many types of social interactions among humans relate to computerized agents as well. In my work I investigate computational aspects of two common social interactions, namely voting and collaborative search. I also propose to solve my suggested problems without many relaxing assumptions in order to come as close as possible to real-world settings. Hence, I concentrate on settings of imperfect information which I model using probabilities.

Voting

Reaching a collective decision is a very common social interaction among people. In many multi-agent environments it is also desirable to have a mechanism which enables the agents within a system to make a collective decision on a given issue. The means by which such a collective decision is made is typically a *voting procedure* (Brams and Fishburn 2002). A classic, much studied issue in the political science literature is the design of voting procedures that, given the preferences of voters within a system, will result in an outcome that will be acceptable to most of the voters, i.e., will as closely as possible reflect the preferences of voters. I investigate computational aspects of voting procedures, with the presence of imperfect information about the exact preferences of the agents. I model this imperfect information using probabilities and the research question addressed is: given incomplete information about the voters' preferences and a particular voting procedure, how difficult is it to compute the probability that a particular candidate will win? This question arises once we are able to gather at least probabilistic knowledge on every voter's preferences.

I also uses another probabilistic model, where only the probability that an alternative will be preferred over another is known. This information is useful in the linear order and cup voting protocols, which are widely used in sports tournaments. In these settings the problem is not only to calculate the probability of an alternative to be chosen but also the possibility of malicious manipulation by the election organizers.

What has been done

The following results were published in (Hazon et al. 2008b). I introduced a polynomial algorithm to solve the problem of computing the probability that a given candidate will win when the number of candidates is a constant. However, when the number of candidates is not bounded, I proved that the problem becomes #P-Hard for the Plurality, Borda, and Copeland voting protocols. In addition I showed that even evaluating if a candidate has any chance to win is NP-Complete for the Plurality voting protocol, in the weighted voters case. I introduced a polynomial algorithm for this problem when the voters' weights are equal.

As for the second model, in (Hazon et al. 2007) I presented some analytical results relating to the complexity of finding and verifying the voting agenda. While I showed that verifying an agenda can be done in polynomial time, I also gave hardness results which lead to conjuncture that the general problem of manipulating an election agenda with incomplete information is NP-Hard to compute. I developed heuristics for agenda rigging, and investigated the performance of these heuristics for both randomly generated data and real-world data from tennis and basketball competitions.

Future directions

As for the first model, I would like to extend my current analysis to more voting protocols. I would also like to improve the results achieved for the current voting protocols: where I prove that the problem is #P-Hard it would be useful to have an approximation algorithm (or to prove that one cannot be found); even where the problem is in P, my algorithm may have an impractically large running time. I intend to empirically learn when the algorithm has practical running time, and when it does not. The next step is to develop heuristics that may yield more efficient algorithms which yield the correct answer for most of the cases.

As for the second model, I currently only have strong evidence that the agenda rigging problem is hard, since I have proven that weaker versions of the problems are NP-Complete. I would still like to compile a formal proof that the original problem of agenda rigging is NP-Complete. Another possible direction is to test my manipulation agenda problem under restricted settings, such as a fixed number of voter types.

Collaborative search

Frequently, in order to successfully complete their task, a team of agents may need to *explore* (i.e., search) their environment and choose among different available options. For example, a team of agents seeking to purchase a product over the internet needs to query several electronic merchants in order to learn their posted prices; a team of robots searching for a resource or a tangible item needs to travel to possible locations where the resource is available and learn the configuration in which it is available as well as the difficulty of obtaining it there. In these environments, the benefit associated with an opportunity is revealed only upon observing it. The only knowledge available to each agent prior to observing the opportunity is the probability associated with each possible benefit value of each prospect.

While the exploration in virtual environments can sometimes be considered costless, in physical environments traveling and observing typically also entails a cost. Furthermore, as any agent travels to a new location its cost of exploring other unexplored locations changes. For example, consider a team of Rover robots with the goal of mining a certain mineral. Potential mining locations may be identified based on a satellite image, each associated with some uncertainty regarding the difficulty of mining there. In order to assess the amount of battery power required for mining at a specific location, a robot needs to physically visit there. A robot's battery is thus used not only for mining the mineral but also for traveling from one potential location to another. My research problem is to find optimal strategies for a team of agents acting in such physical environments.

I consider three variants of the problem, differing in their objective. The first, *Min-Expected-Cost*, is the problem of a group of agents that aims to minimize the expected total cost of completing their task. The second, *Max-Probability*, considers a team of agents that is given an initial budget for the task (which it cannot exceed) and needs to act in a way that maximizes the probability it will complete the task (e.g., reach at least one opportunity with a budget large enough to successfully buy the product). In the last variant, *Min-Budget*, the agents are requested to guarantee a pre-defined probability of completing the task, and they need to minimize the overall budget that will be required to achieve the said success probability.

What has been done

The following results will be published in (Hazon et al. 2008a). I first considered the single agent case and proved that in general metric spaces all three problem variants are NP-hard. Thus, I focused on the case where the opportunities are aligned along a path (either closed or a non-closed one) and the cost of observing the true value of any unexplored source depends on its distance (along the path) from the agent's current position. For this case I provided a polynomial algorithm for the *Min-Expected-Cost* problem. I showed the other two problems (*Min-Budget* and *Max-probability*) to be NP-complete even for the path setting. Thus, I considered further restrictions and also provided an approximation scheme. I showed that both problems are polynomial if the number of possible prices is constant. For the *Min-Budget* problem, I also provided an FPTAS approximation scheme, such that for any $\epsilon > 0$, providing a $(1+\epsilon)$ approximation in time $O(\text{poly}(n\epsilon^{-1}))$.

For the multi-agent case, I showed that if the number of agents is fixed, then all of the single-agent algorithms extend to k-agents, with the time bounds growing exponentially in k. Therefore the computation of the agents' strategies can be performed whenever the number of agents is relatively moderate, a scenario characterizing most physical environments where several agents cooperate in exploration and search. If the number of agents is part of the input then *Min-Budget* and *Max-Probability* are NP-complete even on the path and even with a single price.

Future directions

First, I would like to complete the theoretical analysis in order to find an efficient approximation for the *Min-Expected-Cost* and *Max-probability* problems, or to prove they can not be approximated within a constant factor. After laying the theoretical foundations for the problem, the next step to consider is to extend the multi-agent models to scenarios where each agent operates with a private budget, for example, multiple Rovers, each equipped with a battery of its own. In this model a possible policy would be to send one robot on an exploration, and to use another one to perform the task. Therefore, this model incorporates the problem of collaboration among a team of agents in the presence of uncertainty, which has not been sufficiently investigated. I also plan to develop heuristics for the general metric space case (which I proved to be NP-hard) and to empirically test them.

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