Task Allocation in the RoboCup Rescue Simulation Domain: A short note

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1 Introduction

We consider the problem of disaster mitigation in the RoboCup Rescue Simulation Environment [3] to be a task allocation problem where the tasks arrive dynamically and can change in intensity. These tasks can be performed by ambulance teams, fire brigades and police forces with the help of an ambulance center, a fire station and a police office. However the agents don't get automatically notified of the tasks as soon as they arrive and hence it is necessary for the agents to explore the simulated world to discover new tasks and to notify other agents of these.

In this paper we focus on the problem of task allocation. We have developed two approaches, a centralized combinatorial auction mechanism demonstrated at Agents-2001 and a distributed method which helped our agents finish third in RoboCup-Rescue 2001. With regard to task discovery, we use a greedy search method to explore the world– agents count the number of times they have visited each node, and attempt to visit nodes that have been visited the least number of times.

2 Task Allocation

The problem of disaster mitigation in the RoboCup-Rescue Simulation Environment can be thought of as a task allocation problem where the tasks become known at different times and can change in intensity. The tasks can be thought of as civilians who need to be rescued, buildings which are on fire and roads that are blocked. The problem is then how to assign ambulance teams, fire brigades and police forces to these tasks. There are two categories of approaches to assigning agents to tasks: centralized approaches and distributed approaches. We will describe a centralized combinatorial auction mechanism demonstrated at Agents-2001 and a distributed method based on localized reasoning.

2.1 Combinatorial Auction Mechanism for Task Allocation

Combinatorial auctions have been used before for task allocation [2]. In our auction mechanism, the fire station, ambulance center and the police office take on the role of auctioneers, and the ambulances, fire brigades and police forces take on the roles of bidders . The items being bid for are the tasks. At the beginning of each cycle, each free agent makes several bids - each bid consists of a different combination of tasks and an estimate of the cost of performing sequentially the tasks in this combination. For example Fig. 1 shows fire brigades making bids to the fire station on different combination of buildings on fire that it wants to extinguish based on its proximity to these fires. We make an assumption here that each task can be performed by a single agent. This assumption can be removed by making agents bid on combination of roles in tasks.

The auctioneer receives all the bids and determines the winning bids – the set of bids that cover the most tasks and have the least cost . Most optimal winner determination algorithms that have been developed are branch-and-bound algorithms that fall into two broad-categories: those that branch on bids [6] and those that branch on items [1, 5]. Our algorithm, while based on [6], branches on the bidders. This algorithm is based on one assumption:

– At most one bid per bidder wins. This assumption is a fair assumption to make in the rescue domain where the agent does not desire that more than one combination of tasks is assigned to it.

Our algorithm is a depth-first branch-and-bound tree search that branches on bidders. The branching factor of the search tree is $O(b)$, where b is the maximum number of bids that a single bidder makes. It is fairly trivial to see that winner determination can be performed in $O(b^k)$ time where k is the number of bidders. In domains like RoboCup-Rescue, the number of bidders is constant and thus we have a solution to the winner determination problem that is polynomial in the number of bids made by a single bidder.The other prominent algorithms for winner determination [1, 5, 6] all have complexity $O((n+m)^m)$ where n is the number of bids received and m is the number of items(tasks). Clearly, such solutions, though polynomial in domains where the auctioneer has control over the number of items, are exponential in a domain like RoboCup-Rescue where the auctioneer has no control over the number of items that are being bid on.

The key strength of this approach is that it considers all agents bids for multiple combinations of tasks and thus employs global reasoning. But there are several shortcomings of using combinatorial auctions for task allocation:

– **Exponential number of possible bids:** If the bidders bid on each and every possible combination of tasks then we are guaranteed that the solution obtained by winner determination is the optimal solution to the task allocation problem. However, this would lead to an exponential number of bids received by the auctioneer. Hence it was necessary to decide on what tasks a bidder should bid on. We used a heuristic based approach where the bidders bid on combinations of size $< l$. Therefore the number of bids received by the auctioneer is O($m^l * k$) where m is the number of tasks and k the number of bidders. We also restricted the number of bids by not bidding on tasks that are far away.

- **Difficult to make cost estimate:** In highly dynamic and uncertain domains, it is difficult for bidders to make an accurate cost estimate for bids containing many tasks that need to be performed sequentially. This is another reason for restricting the size of bid to l tasks.
- **Domain-imposed communication constraints:** Constraints on communication could impact the use of combinatorial auctions for task allocation. In RoboCup-Rescue, there are two kinds of communication constraints. First, the number of messages heard by any agent is limited, in the 2001 competitions, this number was 4. This severely crippled the allocation mechanism as centers were responsible for receiving information on new tasks as well. In addition, all agents could not communicate to a centralized auctioneer and needed to go through an intermediate center, which slowed down the communication
- **Not globally optimal:** Even if we assume that this mechanism is optimal for each time step (which it would be if there were no restrictions on the bids made), the allocation is not optimal over all time steps.

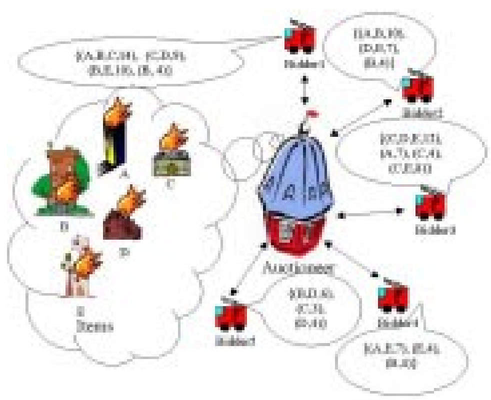

Fig. 1. Auctioning of fires by fire brigades.

2.2 Distributed Mechanism for Task Allocation

The distributed method, based on our agents described in [4], relies on each agent deciding for herself as to which task to perform. This localized reasoning allows agents to evaluate the seriousness of a task before committing to that task. Fire brigades select fires to put out based on intensity and proximity of the fire, ambulances select which civilian to save by evaluating the civilian's health, buriedness and proximity, while police agents choose which road to clear based on number of rescue agents trapped by this road.

The strength of this approach lies in the low number of messages that it requires. A major shortcoming of this approach is that the agents rely on local information and don't concern themselves much with what tasks the other agents were performing. Thus, this allocation scheme is clearly sub-optimal. In practice, by suitably adjusting the local reasoning, satisfactory allocations were found. Agents using this mechanism in RoboCup-Rescue 2001 finished in third place. Nevertheless, the sub-optimality of the distributed allocation is an issue for future work.

3 Conclusion

In this paper we described how search and rescue in the RoboCup Rescue Simulation Environment is a task allocation problem where the tasks arrive dynamically and change in intensity. We explained the need for exploration to discover new tasks and then discussed various approaches to solving the task allocation problem, viz. the centralized combinatorial auction approach and the distributed approach used by our agents in the RoboCup-Rescue 2001 competition where they finished third. In the future, we will be working on allocation methods that combine the benefits of both these approaches.

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