Agent Collaboration and Social Networks

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Abstract- *In this paper we report on preliminary results for evaluating preferences for collaboration among a group of agents who located in a social network. We have implemented a game of boxes that are pushed into holes in a two dimensional world. We vary rations of boxes and holes as well as individuals awareness and information sharing. Our results corroborate intuitive notions and point the way to constructing agent societies with abilities to reason about collaboration.*

1. INTRODUCTION

Collaboration is commonplace in human activity and increasingly in agent-only and human-agent teams. Collaborative technologies are typically considered to fall into three areas: facilitating communication, enhancing information sharing, and improving coordination. These technologies range from real time as in the case of shared visualization tools to asynchronous as in the case of shared databases. Generally, to date, these tools are passive and the initiative for collaboration remains with the human users. Fields such as Computer Supported Cooperative Work (CSCW) and Knowledge Management (KM) explore human motivations for collaboration and produce methods that lead to development of collaboration tools. Furthermore, it is not always known why and how computer systems can act effectively as collaborators. Current computer systems lack capabilities required for working successfully as useful and timely collaborators. In our work we are developing quantification methods for assessing preferences for collaborate based on the agents' notions of payoff. This paper reports on results of a simplified implemented system of collaboration. In a society of agents pursuing agents may be allowed to collaborate, some percentage of the time. The ratio of goals to agents affects the percentage of goals attained via collaboration.

A finding known as the Ringlemann effect reported by Ringlemann in early 1900s observes that as more people are engaged in pulling on the end of a rope, their strength of pulling is inversely proportional to the number of individuals in the group. Similar experiments were performed by Bobb Latane who went on to define the *social impact theory*. Social scientists are continually exploring social influences. Our aim in this paper is more modest. As a first step, we measure the value of collaboration among a number of agents in a simulated grid world of box that are pushed into holes. This paper is in the field of agent-based modeling that has become popular in recent years with wide applications [Bonabeau 2001].

In section 2 of this paper we describe the simulation. In section 3 we describe their possible network of relationships. We offer results of our experiments in section 4 and conclude in section 5.

2. THE SIMULATION

In an implemented simulation, a small group of agents attempt to push boxes into holes on a square grid. The agents begin next to one of the walls, and the boxes and holes are all placed at random locations at least one square away from the walls. All calculations involving distances use the Manhattan metric for simplicity.

During its turn, an agent first looks around for any boxes and holes it can "see." Agents can see up to three squares away from their location. After recording the locations of any boxes and holes, an agent will then

- wander randomly if it doesn't know of any unassigned boxes,
- move towards a box if it knows of one it believes to be unassigned, or
- push a box towards a hole, if it knows of one, or randomly if not.

Finally, the agent exchanges information on the location of boxes and holes with all of its peers based on a variety of social networks it is placed in.

When a box is pushed into a hole, both the box and the hole disappear from the grid. The agents' goal is to fill all the holes in the room, but this goal is complicated by several factors. Since agents can only see a short distance away, they have incomplete knowledge about their environment. Additionally, the agents' knowledge is imperfect in the sense that they only know that a box or a hole is somewhere at the *present* time; another agent might push it around while nobody else is looking.

When an agent sees or hears about a box that it believes to be unassigned, it claims the box for itself. In addition to communicating about the locations of boxes and holes, agents communicate about who has chosen to move a particular box. Therefore, agents who do not talk to each other may spend time pushing around the same boxes. When there are as many boxes as there are agents, this almost always wastes time.

3. Network TOPOLOGIES

In the first set of experiments, agents were organized into groups with a social structure. The four network topologies explored here are unconnected, fully connected, star, and ring graphs. Unconnected social graphs correspond to no collaboration, fully connected to total collaboration, and the other two to information sharing with a time lag. Although more connections mean more information sharing and thus a better chance to reduce the time it takes to achieve the goal, maintaining connections might be costly for an agent. If maintaining connections has an associated cost, some network topologies may not scale with the number of agents.

In the unconnected case, agents do not share information on the location of boxes and holes. It is expected that agents will duplicate each other's work and so the goal will be achieved later on average than if there was cooperation.

In the fully connected case, all agents are connected to all other agents. There is no information lag, but on the other hand, the number of connections scales with the square of the number of agents. Table 1 shows the growth of edges and diameter of the different types of social network, and it also includes the mean time to goal for one group of experiments.

	Growth of Edges	Diameter
Unconnected	0	0
Ring	$O(n)$	$O(n)$
Star	$O(n)$	2
Fully Connected	$O(n^2)$	1

Table 1: Some characteristics of social networks used

The star topology is similar to a hierarchical organization in a corporation when the number of agents is small. It is important to note that since the agents are homogenous, the agent at the hub of the star has no more power than any of the others. The ring topology is a cycle. It was chosen because its diameter (the length of a maximal graph geodesic) grows with the number of agents.

Graphs of the average number of boxes cleared at time t for the different topologies are shown in figure 1. In these simulations, there are 10 agents, 10 boxes, and 10 holes on a 15 by 15 grid. The unconnected agents clearly take more time to clear boxes. The star and ring perform almost equally, trailing the fully connected graph until about t=50, when they start to perform better.

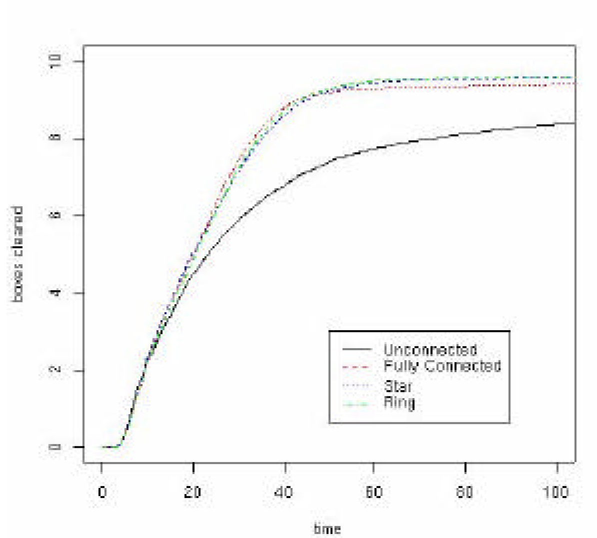

Figure 1: Average number of boxes cleared by time for several social network topologies

This result is puzzling, since one would expect the graph with more connections to do better. One possible explanation is that the fully connected agents are sometimes reluctant to claim boxes to push since they defer to other agents who have already claimed the boxes. In the star and ring case, the time lag on communication may cause agents to claim boxes before they know about other agents who have already claimed them. (Our agents are overcommitted in the sense that once they claim a box, they will always try to push it even if they later hear that another agent has claimed the box.) In some cases, such as when an agent close to a box defers to an agent far away, this difference may be noticeable.

4. COLLABORATION RESULTS

In the next series of experiments, some agents collaborate with each other, and some agents work independently. We examine two notions of payoff from the point of view of a newcomer who has to decide whether or not to collaborate: minimizing the total time it takes to clear all the boxes and maximizing an individual agent's number of boxes cleared. These goals can conflict with each other, since sharing information may decrease the total amount of time it takes to clear all boxes, but not sharing may allow an agent to clear a box itself.

Figure 2 shows how the average time to clear all boxes depends on the rate of collaboration. These simulations take place on a 15 by 15 grid with the number of agents and boxes indicated. There are as many holes as boxes. Collaborating agents have a fully connected topology, and non-collaborating agents are completely disconnected. Thus the results correspond to the unconnected case when the rate of collaboration is 0 and to the fully connected case when the rate is 1. All results are averaged over 1000 runs of the simulation.

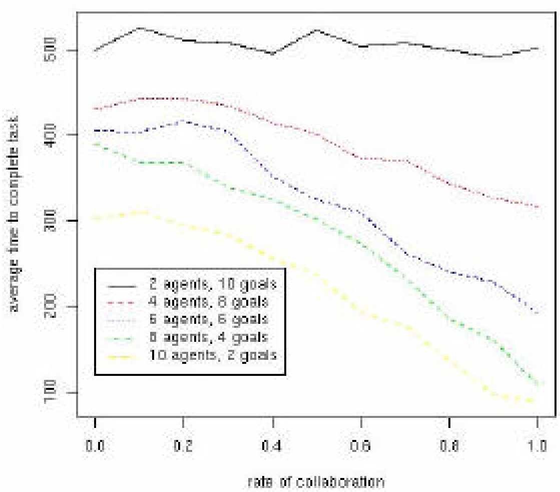

Figure 2: Average time to clear all boxes by rate of collaboration

This figure shows that when the ratio of agents to goals is small, collaboration is irrelevant to the amount of time taken to clear the boxes. On the other hand, when the number of agents is near the number of boxes, collaboration may decrease the mean time to clear all boxes dramatically. If the agents' goal is to minimize the time take to clear all boxes (the agents are altruistic), collaboration is valuable at any rate when the ratio of agents to goals is above some small threshold.

A selfish agent would want to maximize its number of boxes cleared. The percent of cleared boxes per agent is shown in figure 3. Increasing lines correspond to the collaborators, while decreasing ones indicate how well the noncollaborators perform. The collaborators' performance increases up to some asymptotic value, confirming results reported in [Kennedy and Eberhart 2001].

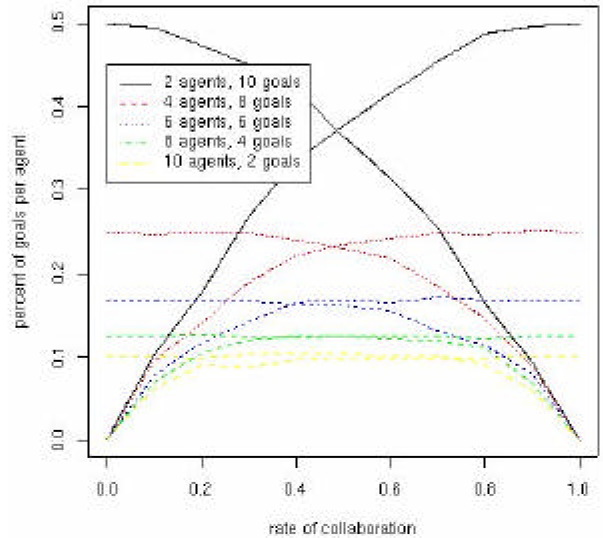

Figure 3: Percent of goals per agent by rate of collaboration

The point where the collaborator and noncollaborator lines meet indicates when an agent would prefer to collaborate in order to maximize their number of boxes pushed. In each case, the crossover occurs at about a 50% rate of collaboration. This means that a new agent will collaborate if about half of its peers are collaborating.

Consider a hybrid between the altruistic and selfish agents above. Such an agent wants to maximize the number of boxes it clears per time. Figure 4 shows how well the collaborating and noncollaborating groups do by rate of collaboration. Again, increasing lines correspond to collaborators.

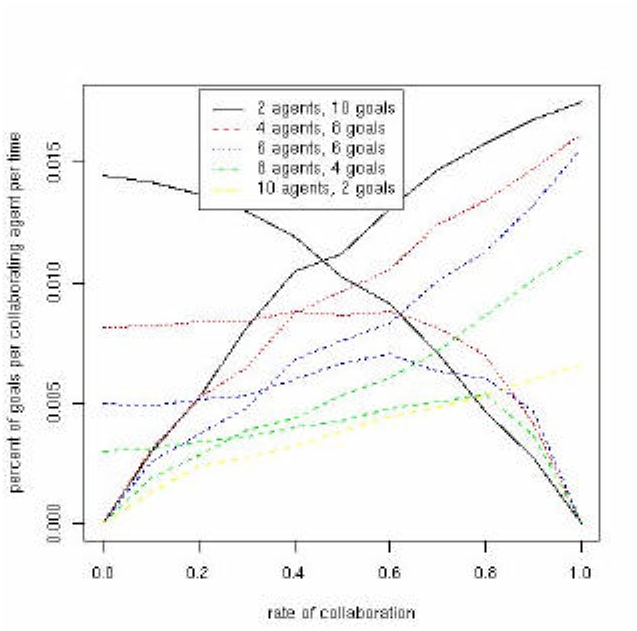

Figure 4: Percent of goals per collaborating agent per time by rate of collaboration

For these hybrid agents, whether to collaborate depends on the ratio of agents to boxes. When this ratio is small, agents begin to refer to collaborate when about half of them are collaborating. But as the ratio of agents to boxes increases, the agents prefer to collaborate when fewer of them are collaborating. For example, the crossover point when there are twice as many agents as goals is less than 30%.

5. CONCLUSIONS

In a series of simulations involving a simple box pushing game, we have investigated how the social network topology affects agents' performance and how agents' preferences to collaborate are affected by external factors. The game resembles the prisoner's dilemma in that it requires agents to decide whether or not to collaborate based on some payoff criterion. Two important criteria are mean time to clear all boxes and number of boxes cleared by an individual agent. When the agents' goal is to minimize the mean time to clear all boxes, they can clearly do better by collaborating. Two types of social network we looked at, fully connected and star, did not differ very much. If social connections are associated with a cost of upkeep, then networks whose number of edges grows more slowly may be preferred. The main point of investigation was to explore agents' preferences to collaborate. These preferences depend highly on the agents' notions of payoff. Altruistic agents, who want to minimize the time taken to clear all boxes, prefer to collaborate when the ratio of agents to boxes is above some threshold. Otherwise, they are indifferent. Selfish agents, who want to maximize their individual number of boxes cleared, prefer to collaborate when about half of the group is collaborating irrespective of the ratio of agents to boxes. Hybrid agents, who wish to maximize their number of boxes cleared per time, collaborate more readily when the ratio of agents to boxes is large. These results are useful for constructing agent societies that are able to reason about collaboration [Prietula, Gasser, and Carley, 1998].

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