Supporting Collaborative Activity

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Abstract

This paper presents a model—SharedActivity—for collaborative agents acting in a group. The model suggests mental states for agents with different levels of cooperation and permits the formation of groups in which members increase individual benefits. Unlike previous models, the model covers group member behavior where group members do not have a joint goal, but act collaboratively. The model defines key components of a collaborative activity and provides a platform for supporting such activity. We studied the behavior of the model in a simulation environment. Results show how the benefit attained by cooperation is influenced by the complexity of the environment, the number of group members, and the social dependencies between the members. The results demonstrate that the model covers social behavior both in settings previously addressed, as well as in novel settings.

Introduction

Group effort can be expressed as the series of activities carried out by group members during the existence of the group. The quality of the cooperation in the group depends on several factors such as the distribution of the activities in time and space, the number of participants, the relationship between the members, structural complexity features (interaction, heterogeneity), the level of specialization among participants, the uncertainties posed by the field of work, etc. (Carstensen & Schmidth 1999).

Psychologists often classify groups according to the purposes for which the groups are formed. Two such purposes are *task* groups, and *treatment* groups (Toseland & Rivas 2001). A task group is formed to accomplish a joint goal and thus the benefit of each member is immediately linked to the success of the joint task. In contrast, a treatment group is formed where the purpose of the members is to meet individual needs. A treatment group is formed as a result of sharing common resources, situations, experiences, etc. Examples include: students working in the same lab, roommates sharing an apartment, or a group on a group-tour.

Previous work (Levesque, Cohen, & Nunes 1990; Kinny *et al.* 1994; Grosz & Kraus 1996) has proposed explicit well-grounded models of task-group distributed problem-solving. These models address essential characteristics of cooperative work and support the design and construction of collaborative systems. Using such models for multi-agent systems enhances the cooperation capabilities of the individual actors working towards a joint goal (Jennings 1995; Tambe 1997). Hence, previous models—concerning only problem-solving in task Groups—do not support collaborative problem solving in treatment groups, in which members have the motivation to increase their own benefits, yet may still benefit from working with others.

Consider, for example, an agent searching for information for its own goals, which discovers information which interests another agent during the search process. By notifying the other agent about this information, it reduces the other's search cost. Repeated mutual interactions of this type will increase both parties' utilities. Yet the agents do not have a common goal, and thus existing collaborative models do not apply. A new model is needed to support the development of agents capable of participating in treatment groups.

In this paper, we present the SharedActivities model of both task and treatment groups. The goal is to provide a new and better platform with a high degree of flexibility in collaborative activity. While our model is novel and is able to account for group behavior previously not modeled, several characteristics of former models (e.g., types of intentions, mutual beliefs), are re-used.

We investigated the behavior of our model empirically, by applying it in a simulation of a small group visiting a museum. Our experiments test how various environmental settings influence the agents' benefits when they are engaged in the task group, the treatment group and when they are not active in a group. In addition, we investigated how the level of cooperation of the members is influenced by the environmental settings.

Background

The SharedActivity definition (see next section) is based on studies of human groups. Toseland and Rivas (Toseland & Rivas 2001) compare between features of treatment and task groups: Members of treatment groups are bonded by their common needs or situations, while members of task groups are bonded by a joint task or goal. In treatment groups, roles evolve through interaction, and communication patterns are flexible. In task groups, roles are frequently assigned by

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the group, and communication patterns are focused on the particular task. Treatment groups often have tend to have informal and flexible procedures, while task groups are more likely to have formalized rules for decision making. Treatment groups are often composed of members with similar concerns while task groups are often composed of members with the necessary resources and expertise to achieve the group's joint goal. Finally, the criteria for evaluating success differ between treatment and task group. Treatment groups are successful to the extent that they help members meet their individual goals. Task group are successful when they achieve group goals.

Previous models for supporting groups are based on features of task groups. Levesque et al. (Levesque, Cohen, & Nunes 1990) suggest notions of joint commitment and joint intentions and study the ways in which they relate to individual commitments of group members. These types of commitments are essential when a group's success is attained by satisfying a joint goal. Other models (Grosz & Kraus 1996) take the advantage of group commitments to provide collaborative planning processes for achieving the joint goal. These include processes for how to perform activities and allocate tasks, as well as processes for coordination. However, the focus of the processes is on the team goal, not individual goals.

Recent work (Lesser & Wagner 2002; Sen & Dutta 2002; Talman, et al. 2005) has proposed models in which agents are allowed to change their level of cooperation over time as a function of their environment. In these models, the agent's cooperation measure depends on its personality and past experiences, as well as the cost of helping. This work investigates the tradeoff between selfishness and helpfulness in environments in which agents are uncertain about the cooperative nature of others in the system. Yet, these works do not provide a model to support a group formation by such agents. The model presented in this paper deals with agents who act in a group but are able to adjust their cooperation level to the environment over time.

The SharedActivities Model

The SharedActivities model is intended to be used in guiding the design of agents, by providing a specification of the capabilities and mental attitudes that an agent must have when it works as a part of a group. To motivate the discussion, we start with an informal example of a small group visiting a museum. The model was tested in a simulation of this task (see experiments section). We refer to this example throughout the paper.

An Example of a Collaborative Activity

Our example is aimed at extending the PEACH technology for museum visits. PEACH (IRST 2005) offers adaptive multimedia presentations as the visitor moves around in a museum. One specific challenge in this project is to develop technology that supports group visits to the museum. In particular, to support a visit by groups that do not have a joint goal but instead have a common bond, e.g., a family or friends that visit the museum together. The idea is that the technology may help integrate their experiences (Stock *et al.* 2005). The SharedActivity model aims to eventually support several situations of cooperation in the museum, examples include:

- *role-based presentation* that consider the role of the visitor in the group and provide her with information appropriate for the role. For example, for the visit of a family, the system will be able to explain to a parent about the objects that fascinated her child.
- *coordinate presentations* that inform the visitor about the objects which interested her group members. For instance, the system will be able to show a visitor what was interesting for her husband. On the other hand, if the visitor discovered an object that her husband has not seen yet, but may interest him, she will be able to send him relevant information.
- *generate group summaries* that take into account the different information presented to different members. For instance, it will be able to integrate presentations among the group's members and to support group summaries at the end of the visit.
- *helpful behavior capabilities* that reason about improving others' experiences. For example, if a team member detects an interesting activity in the museum that other members may like, but this area is too crowded, the system will be able to inform the others about this problem.

Overview of the Model

Figure 1 lists key components of mental states of members when they have a collaborative activity. First, cooperation implies the ability of the agents to identify themselves as members of a group (Item 1). Second, when the members engage in interaction, they may exchange information through verbal and nonverbal communication processes. This maintains the group. The belief that members intend to be a part of the group gives the motivation to interact (Item 2). Third, each individual in the group is characterized by life histories, development patterns, needs, goals, and behavior patterns. These characteristics should be known by the other members during the collaborative activity and are represented in each member's profile. Thus, the members must have beliefs concerning a a profile of the others (Item 3). The profile may be given explicitly or implicitly (e.g., learning the profile by observation, overhearing, etc.). Fourth, dependence refers to the relation in which the utility that one member obtains from its own behaviors is affected at least partly by the activities of another party. Mutual dependence means that the utilities of all the parties are determined by their collective behavior (Derlega & Grzelak 1982) (Item 4).

To have a collaborative activity, a group of agents must have

1. mutual belief that all the group's members are part of the group

2. mutual belief that all the group's members have the intention that the group be maintained

3. belief in a (partial) profile of other members

4. mutual dependence

Figure 1: Key components of collaborative activity.

Note that the key components are suitable for both treatment and task groups, as they do not specify the purpose for which the group is formed. Furthermore, in former models for supporting task groups, the agents hold the above mental states implicitly: First, they have joint intentions to achieve a joint goal which entails their beliefs about the members of the group and their intention to maintain the group during the performance of the task. In addition, the agents hold beliefs about the intentions of the other agents, their capabilities and their situations which can be considered as the profile. Since the members have a joint goal and their utility is attained by satisfying this goal together, their utilities are determined by their collective behavior (i.e., they are mutually dependent). Thus, a task group is a special case of SharedActivity.

In the museum example, visitors may cooperate if they enjoy sharing their experience. In such a case, they must identify the group members who enjoy sharing the experience. Their intention in maintaining a group and maintaining beliefs about the others' profile entails information exchange. They believe that by sharing the experience they enhance the experience of each individual as well as of the group.

The Model Formulation

We use standard operators for intention and belief (Grosz & Kraus 1996). The operator Int.To$(A_i, \alpha, T_n, T_\alpha, C)$ represents A_i's intentions at time T_n to do an action α at time T_α in the context of C. Int.Th$(A_i, prop, T_n, T_{prop}, C)$ represents an agent A_i's intention at time T_n that a certain proposition $prop$ holds at time T_{prop} in the context of C. The potential intention operators, Pot.Int.To$(\dots)$ and Pot.Int.Th$(\dots)$, are used to represent the mental state when an agent considering adopting an intention but has not deliberated about the interaction of the other intentions it holds. The operator Bel(A_i, f, T_f) indicates that an agent A_i believes the statement expressed by formula f at the time T_f (we abuse the notation, and the formula f is not really the argument, but its name $'f'$). MB$(\dots)$ represents Mutual Belief. In addition, the operator Do(A_i, α, T_α) holds when A_i performs action α over time interval T_α.

The formal definition of Shared Activity (SA) is given in Figure 2 (clauses 1–4 are equivalent to the cases 1–4 of Figure 1). It specifies those conditions under which group $\mathcal{A}$ can be said to have a collaborative activity $\mathcal{C}$, at time $T_\mathcal{C}$. The activity $\mathcal{C}$ represents a set of actions which is carried out by the group members during the collaborative activity. The collaborative activity may be associated with several properties such as constraints. Doing an action in the context of the collaborative $\mathcal{C}$ must consider these properties. For example, a visit by a parent and child to a museum consists of the actions of looking at objects, but may have the constraint that the parent and the child cannot move away from each other. We use the notation $\mathcal{P}$ to represent the profiles of the members and we denote by P_i^j the A_i's beliefs about A_j's profile. The operator $member(A_i, \mathcal{A})$ in the definition holds if A_i member of $\mathcal{A}$. In the fourth clause, the mutual dependence is specified by the utility of A_i from being a member of $\mathcal{A}$.

Axioms

An agent A_i may decide to adopt an intention to do an action α as a part of the SA. The agent's decision must take

$SA(\mathcal{C}, \mathcal{A}, \mathcal{P}, T_\mathcal{C})$

1. $\mathcal{A}$ has MB that all members are part of $\mathcal{A}$:
MB$(\mathcal{A}, (\forall A_i \in \mathcal{A}) member(A_i, \mathcal{A}), T_\mathcal{C})$

2. $\mathcal{A}$ has MB that the group be maintained:
MB$(\mathcal{A}, (\forall A_i \in \mathcal{A}) Int.Th(A_i, member(A_i, \mathcal{A}), T_\mathcal{C}, T_{mem}, \mathcal{C}))$

3. Members of $\mathcal{A}$ have Bel about the profile:
$(\forall A_i \in \mathcal{A})Bel(A_i, (\forall A_j \in \mathcal{A})(\exists P_i^j \subseteq \mathcal{P}), T_\mathcal{C})$

4. $\mathcal{A}$ has MB that being a member obtains better utility:
MB$(\mathcal{A}, (\forall A_i \in \mathcal{A}) utility(A_i, member(A_i, \mathcal{A})) \geq utility(A_i, \neg member(A_i, \mathcal{A})), T_\mathcal{C})$

Figure 2: Shared Activity

into consideration the benefit and the cost of performing α. Because of the mutual dependence between the members, when A_i performs the action α, $A_j \in \mathcal{A}$ may obtain a reward from α performance. The mutual dependence between the agents is attained by the benefit function, $b_i^j(\alpha)$, and the cost function, $c_i^j(\alpha)$, where i denotes the agent A_i which is the performer, and j denotes the agent A_j.

A1. Cooperative act axiom. An agent A_i is cooperative when its activities do not only contribute to its own utility but also to the utilities of the other members. This axiom states that if A_i believes that it obtains some benefit from performing α and A_i also believes that A_j obtains some benefit from it, then there are two cases of a cooperation. The first case states that if A_i believes that A_j is damaged from performing α by itself then A_i considers doing α. In the second case both agents, A_i and A_j, are are not damaged from performing α and there are three options: First, A_i may consider doing α by itself. Second, A_j adapts a potential intention that α will be done by A_j. Third, α will be performed by A_i and A_j jointly.

$(\forall \alpha \in \mathcal{C}, (\forall A_i, A_j \in \mathcal{A}), T_n)$
[[Bel$(A_i, b_i^i(\alpha) - c_i^i(\alpha) > 0, T_n) \wedge$
Bel$(A_i, b_i^j(\alpha) - c_i^j(\alpha) > 0, T_n)] \Rightarrow$
case 1: *"A_j loses from performing α by itself"*
[Bel$(A_i, b_j^j(\alpha) - c_j^j(\alpha) \leq 0, T_n) \Rightarrow$
Pot.Int.To$(A_i, \alpha, T_n, T_\alpha, \mathcal{C})] \otimes$
case 2: *"A_j obtains benefit from performing α by itself"*
[Bel$(A_i, b_j^j(\alpha) - c_j^j(\alpha) > 0, T_n) \Rightarrow$
[Pot.Int.To$(A_i, \alpha, T_n, T_\alpha, \mathcal{C}) \vee$
Pot.Int.Th$(A_i,$ Do$(A_j, \alpha, T_\alpha), T_n, T_\alpha, \mathcal{C}) \vee$
Pot.Int.Th$(A_i,$ Do$(\{A_i, A_j\}, \alpha, T_\alpha), T_n, T_\alpha, \mathcal{C})]]]

Note that the above axiom may lead to the formation of a task group which is handled by previous models. Such an opportunity for forming a task group occurs when A_i and A_j mutually believe that they have utility from performing α by themselves and both of them adopt intentions as given in the third option of the second case. However, we leave the discussion of how agents can recognize and take advantage of such opportunities to future work.

In the museum example, coordinated presentations are a type of cooperative activity. If A_i looks at an object which is interesting for both A_i and A_j, both of them obtain a benefit, as they may share their experience. In the case that A_j is far from the object and her cost to arrive at the object is too high then A_i may look at the object for both of them and will notify A_j about information which is interesting for A_j.

A2. Helpful-behavior act axiom. An agent A_i may help another member A_j, even if A_i does not obtain any benefit from the performance of α. The following axiom states that an agent A_i will consider taking action α which may decrease its utility, if it believes that its cost is bounded by some lower bound (LB). Also, A_i believes that, by performing α, A_j obtains significant benefit (i.e, A_j's greater than ϵ_1.) In addition, A_i believes that its loss from performing α is significantly smaller than A_j's loss when A_j performs α.

$$
\begin{aligned}
&(\forall \alpha \in \mathcal{C}, (\forall A_i, A_j \in \mathcal{A}), T_n) \\
&\quad [\text{Bel}(A_i, LB < b_i^i(\alpha) - c_i^i(\alpha) \leq 0, T_n) \wedge \\
&\qquad \text{Bel}(A_i, b_i^j(\alpha) - c_i^j(\alpha) > \epsilon_1), T_n) \wedge \\
&\qquad \text{Bel}(A_i, b_j^j(\alpha) - c_j^j(\alpha) < b_i^i(\alpha) - c_i^i(\alpha) + \epsilon_2, T_n) \Rightarrow \\
&\qquad\quad \text{Pot.Int.To}(A_i, \alpha, T_n, T_\alpha, \mathcal{C})\ ]
\end{aligned}
$$

The role-based presentation, in the museum example, is a type of helpful-behavior act. In such a case, A_i looks at objects which does not interest it but that interests A_j, it does it in order to increase the experience of A_i.

A3. Selfish act axiom. The following axiom states that an agent A_i will consider taking an action α when A_i believes that it obtains some benefit from α performance but A_j does not obtain any benefit. Also, as a member of the group, A_i cares that A_j will not be damaged from the performance of α (i.e., the loss of A_j is greater from some ϵ_3.)

$$
\begin{aligned}
&(\forall \alpha \in \mathcal{C}, (\forall A_i, A_j \in \mathcal{A}), T_n) \\
&\quad [\text{Bel}(A_i, b_i^i(\alpha) - c_i^i(\alpha) > 0, T_n) \wedge \\
&\qquad \text{Bel}(A_i, \epsilon_3 < b_i^j(\alpha) - c_i^j(\alpha) \leqslant 0, T_n) \Rightarrow \\
&\qquad\quad \text{Pot.Int.To}(A_i, \alpha, T_n, T_\alpha, \mathcal{C})]
\end{aligned}
$$

In the museum domain, looking at an object which is not interesting for other members in the group is a selfish act.

The values of ϵ_k $(k = 1, 2, 3)$ and LB in the above axioms are influenced by several parameters (Derlega & Grzelak 1982) such as moral principles, the relationship between the members, the members' reputation, etc.

Experimental Design and Analysis

To explore the behavior of the SharedActivities model we developed a simulated museum test-bed, in which we could vary different factors influencing the behavior of the agents. The museum was represented by a weighted connected graph. Each vertex in the graph denoted an object of interest. As objects are typically clustered together in rooms (and are then freely viewable from different positions in the room), vertices were organized into small cliques. Common vertices between cliques simulated doorways. In the experiments below, we used museums with 10 rooms, and 8 pictures in each room.

We simulated agents which toured the graph. The agent was able to perform two actions: either to stop near a picture in order to look at it or to go to another picture. The agent's cost in arriving at a picture was a function of its distance from the vertex. The agent obtains a benefit when it arrives at the vertex. Each agent had a profile that matched its interests with vertices: looking at a picture yielded a utility in the interval $[-3, 7]$, for each time-unit the agent spent at the vertex. Prior to arrival at the vertex, the agent could only estimate the utility that could be generated by the visit, with some uncertainty (which we vary in the experiments). The objective of each agent is to maximize its utility from touring the graph, in a fixed amount of time.

We simulated three types of groups. Two of them were collaborative and used mental states of the SharedActivity model. In all groups, members were acquainted with their profiles (with some level of uncertainty, see below). Each member could know its location within the graph and the location of the others. Thus, they could calculate the cost and the benefit of the other members (if they wished).

The first group, denoted *SA*, acted exactly according to the axioms of the SharedActivity model (ϵ_k $(k = 1, 2, 3)$ and LB were constants, $\epsilon_k = 5$, $LB = 2$). In this case each member tried to maximize its own benefit, and cooperated with others according to its individual decisions which were based on its situation and its beliefs about the others. Cooperative or helpful activities took the form of visiting vertices that were beneficial for other members (and sometimes only to them), at a cost to the visitor. They interacted with the other members during the visit and informed them about visited vertices. This sharing of information reduced the uncertainty of the other members as to the utility of visiting vertices, and thus affected their planned paths.

The second group, denoted *SP*, acted as a task group, with a joint goal of maximizing total group benefit by visiting as many utility-maximizing vertices as possible. Prior to this graph traversal, the graph was divided into equal-length paths, and these were allocated to the group members. This task allocation process considered the profile of the agents and each agent was responsible for touring the part that maximized its individual utility (based on its profile). However, each agent was also committed to visiting the vertices with pictures that interested other agents in the group and to notify them about the relevant information.

The third type was a group of purely self-interested agents that did not hold the mental states of the SharedActivity model, and therefore could not cooperate in maximizing their own utilities.

We ran extensive experiments using this environment, varying (1) $Time \in [50, 450]$, the time allotted for a tour; (2) $CostS \in [0, 5]$, the cost of each step in the museum, in the range; (1) $RoomN \in [1, 9]$, the number of rooms (out of the 10) to be viewed in the museum, essentially controlling how distributed the agents became; (3) $AgentN \in [1, 10]$, the number of group members; (4) $UncerL \in [0, 6]$, the level of uncertainty regarding the expected benefit of visiting vertices (given as a distance marking a range around the actual interest level).

The goals of the experiments were to compare between the average benefits of the three different groups and to test the behavior of the SA model at various environmental settings. The total number of combinations we tested exceeded 30,000. For each such combination, we generated 36 trials, for a total of just over a million runs. We report on a small subset of these results, highlighting key lessons below.

We begin by examining the average benefit obtained by the different groups, as a function of the allotted time. Our

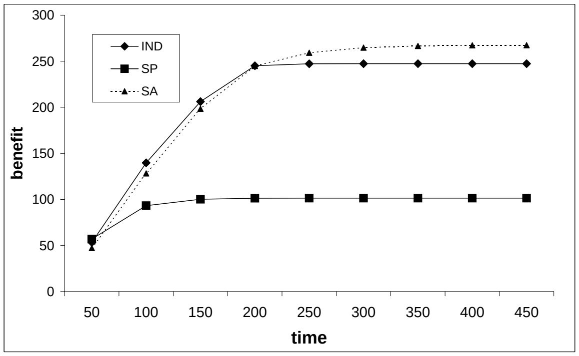

Figure 3: Comparison between the average benefits as a function of the time ($Time = [0, 450], CostS = 1, RoomN = 5, AgentN = 7, UncerL = 2$)

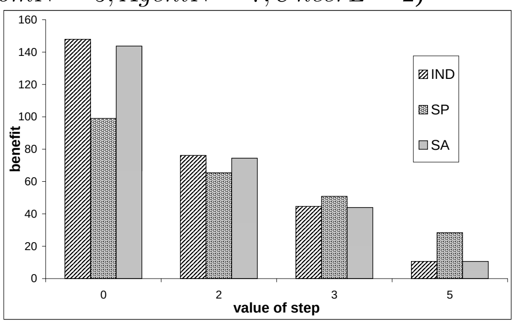

Figure 4: Comparison between the average benefits as a function of step value ($Time = 100, CostS = [0, 5], RoomN = 5, AgentN = 5, UncerL = 2$)

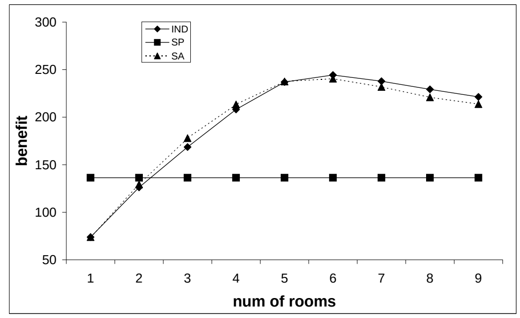

Figure 5: The average benefit as a function of number of rooms ($Time = 200, CostS = 1, RoomN = [1, 9], AgentN = 4, UncerL = 2$)

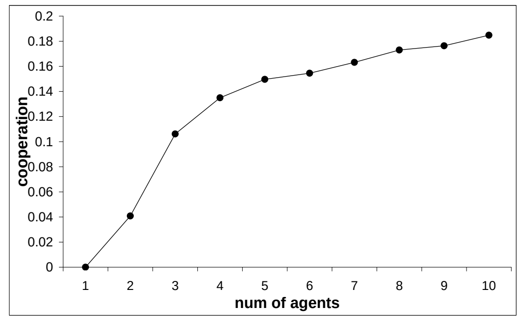

Figure 6: The influence of the number of agents on the time that an agent of SA group invests in others ($Time = 300, CostS = 1, RoomN = 3, AgentN = [1, 10], UncerL = 2$)

hypothesis was that when the agents have enough available time, the SA group obtains a better benefit because they utilize their free time to help others, and to improve their tour according to the information they received from others.

Figure 3 shows the average benefit obtained by the different groups. The x axis marks the allotted time. The y axis marks the average utility. Each data point averages 36 trials. When the allotted time is between 100 to 450 the average benefit of the SA group and individual agents outperforms the average benefit of the SP group. When the allotted time is between 100 to 200 units then the benefit of the individual agents outperforms the benefit of the agents in the SA group. However, as predicted by our hypothesis, when the agents have enough time (i.e., greater than 200) the SA group significantly outperforms the individual agents (paired t-test, p value< 0.001).

Figure 3 also shows that the SP group outperforms the individual and the SA group when the allotted time is less than 100 (and as we see below, in Figure 4, also when the cost of moving between vertices is high). In such settings, the SP group attains better benefit since pre-allocating the tasks among group members optimizes allocation and utilizes the resources more efficiently. The benefit obtained by the agents as a function of a step cost is given in the graph in Figure 4.

We also tested how the number of rooms influences the benefits. Our hypothesis was that having a large number of rooms increases the benefit as they may find more pictures which fit their profile. However, if the museum is too large they have larger cost due to travel time and distance and thus their benefit decreases. The results (Figure 5) confirm this hypothesis. The SA group and the individual agents have maximum benefit at 5 rooms, beyond this their benefit decreases. The benefit of the SP group was fixed because they share the rooms between them and are committed to these rooms.

We then turned to study the effect of the number of the agents in the group on the benefits gained. We anticipated that increasing the number of the agents in the SP group will decrease the benefit since the members that complete their commitments become idle. Also, they share their benefits. We also expected that the benefits of the SA group would not change, because as the number of agents increases, each obtains more benefit from the cooperation. On the other hand, they invest more time in helping members. Figure 6 validates the hypothesis that as the number of agents increases, they invest more time in helping others. The y axis of the graph describes percentages of time that an agent in the SA group spent on other members in the group.

Figure 7 describes percentages of time that an agent of the SA group assists others as a function of uncertainty. There is a negative correlation between the percentages of assistance and the estimated quality of each picture. We postulate that this is the same as the influence of decreasing time. Results also show that the uncertainty about the environments decreases the benefits.

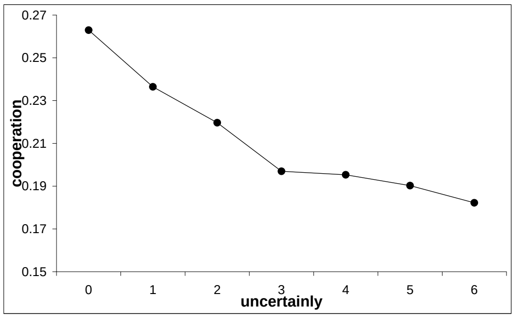

Figure 7: The influence of the uncertainty on the time that an agent of SA group invests in others ($Time = 300, CostS = 1, RoomN = 5, AgentN = 6, UncerL = [0, 6]$)

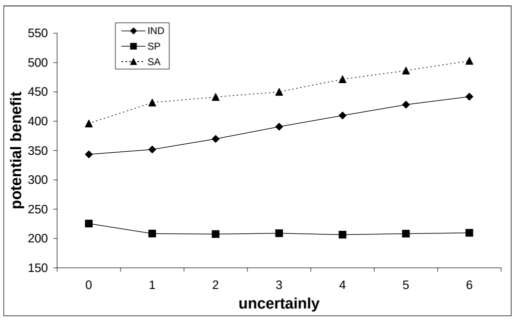

Figure 8: Comparison between the average potential benefit as a function of uncertainty ($Time = 300, CostS = 1, RoomN = 5, AgentN = 6, UncerL = [0, 6]$)

We investigated an additional type of utility, called *potential benefit*. Potential benefits were gained by an agent when it looked at a picture that might interest another member, giving it the opportunity to exchange impressions about the picture with another agent at a future point in time. Since individual agents do not consider others, they may look at pictures which interest other agents without knowing it, yet realize this potential later on. Thus, we also considered a potential benefit for this type of agent.

The graph in Figure 8 shows how uncertainty influences these potential benefits. To our surprise, the potential benefit of the agents of the SA group and the individual agents monotonically *increase* with uncertainty. Furthermore, these potential benefits are significantly higher than the potential benefit of the SP group which decreases as the uncertainty increases. The explanation for these results is that the agents of the SA and IND groups do not intend to realize potential benefits, but uncertainty decreases their intended (planned) utilities, and increases the unintended utilities. In contrast, the agents of the SP group are committed to others and thus they intend to gain potential benefit. Since uncertainty interferes with their planned utility-maximizing paths, their benefit from this source decreases.

To summarize, the results show that the SA model acts like the individual group in many ways, yet it also behaves at times like the SP task-group models. Moreover, the model is able to increase productivity even in cases where the SP model and individual models do not.

Conclusions

We presented a model of collaborative activity for supporting cooperation between group members consisting of humans and computer systems. Based on studies from psychology, the model suggests key components and mental states for agents who act in cooperation. In contrast to former models, it deals with both treatment and task groups and allows different levels of cooperation.

We investigated the behavior of the model in a simulation environment and compared between benefits attained by being members in a treatment group or a task group, or by acting according to purely selfish motivation. Results show that the benefit is influenced by different parameter settings. In the case of sufficient resources to achieve individual goals, the treatment group obtains the best benefit. However, when the resources are limited, it is preferable to act as a task group.

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