Human-Agent Team Formation: An Empirical Study

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Abstract

This paper studies the decision-making strategies people deploy when they interact in groups comprising both human and computer agents. It focuses on settings where actions are occurring at a fast pace and decisions must be made within tightly constrained time frames, under conditions of uncertainty and partial information. Participants can form teams by negotiating over splitting rewards that they can obtain by successfully completing joint tasks. However, members may defect from their teams by accepting offers from non-team members. In this paper the authors present a behavioral study that measures the extent to which social factors such as trust and fairness affect people's commitments to their teams when these include both computer agents and humans. Results show that people offer significantly less benefit to agents than to people when forming teams. However, people are as loyal to agent-led teams as they are to human-led teams. These results have implications for the design of decision-making strategies in mixed-initiative systems for building trust and cooperative relationships between humans and agents.

1 Introduction

Computer systems are increasingly being deployed in group settings in which they interact with people in carrying out tasks [10, 8]. Examples of group activities in which computer systems participate, whether as autonomous agents or as proxies for individual people, include online auctions, hospital care-delivery systems, (military) training simulations. Many such group interactions occur within *fast-paced* domains in which conditions change rapidly, actions occur at a fast pace, agents are distributed and decisions must be made within tightly constrained time frames. For computer agents to be successful in these heterogeneous group settings, they need to act appropriately, meeting people's expectations of group members. It is therefore important to understand the decision-making strategies people deploy when computer agents are among the members of the groups in which they work. For the remainder of this paper we will use the term 'agent' as an abbreviation for computer agents.

This paper presents an empirical study of the way social processes affect decision-making in two types of situations that need to be handled appropriately for effective group interaction. The first is *team formation*, the process by which individuals create teams in order to carry out joint tasks. The second is *intention reconciliation*, in which participants need to manage conflicts among commitments made to different teams. Both of these issues have been studied in settings involving solely agents or humans, but not in heterogeneous settings that involve both. Work on mixed systems including both agents and humans has shown that humans perceive the benefit of collaborating with agents differently than collaborating with people [5], and that this affects the strategies agents should adopt for effective interaction. Other works have identified the benefits to using agents to train human negotiators [7] and to model gender differences in human-agent negotiation strategies [6]. None of these works considered team formation and they were restricted to two-actor settings. The contribution of this work is that it identifies the extent to which these issues affect behavior in heterogeneous systems.

Table 1: Details of the CT Package Delivery Game

participants	humans & agents
package pickup	scattered large (LP) and small (SP) packages
package delivery	one central depot
delivery payoff	SP: 3, LP: 60 or 180
forming teams	negotiate contract over split of payoffs
defection	accept outside offers
choose members	ask anyone

Participants in our experiment formed teams by agreeing upon a split of the payoff that the successful delivery of a large package would yield. They could choose to opt-out of their agreement at any point and dissolve their teams, or they could forgo working with others altogether and choose to work individually. We studied the effects of three types of social factors on team formation and intention reconciliation: trust relationships, fairness considerations, and the way people treat agents differently than people.

Our study was conducted using human subjects of varying ages and social-economic backgrounds, who interacted with each other using a an open source research test-bed for studying human-agent decision-making. This test-bed consisted of a six-player computer game that provided an analogy to the way tasks, goals and resources interact in real-world group interactions. To isolate the effect of how people perceive agents compared to humans, we did not use computational strategies in the empirical study, but made some of the human participants appear as agents to other participants. Our results show that the offers that people make to other people are significantly more fair than the offers they make to those they perceive to be agents. However, people did not discriminate against agents when deciding whether to join agent-led teams, and they were just as committed to these teams as they were to human-led teams. In addition, people who were more likely to create and join teams were more successful than those who were more likely to act individually, despite the high degree of uncertainty that was associated with the domain. Thus, people favor the long term benefits of cooperative behavior over acting selfishly and incurring rewards in the short term. Lastly, we found that along with the benefits they received, the extent to which people were able to form long lasting relationships in the past was an important factor in their decision-making.

These results have implications for agent designers who are developing agents that interact with people in fast-paced domains. The results demonstrate that humans are willing to take part in group activities led by computer agents, and that they are as loyal to agent-led teams as they would be to human-led teams in such settings. In addition, to be more successful, agents should be designed to make their actions appear as human-like as possible to other people.

This paper is organized as follows. First, in section 2, we will introduce our experimental framework. The empirical methodology will be addressed in section 3. We will present our results in section 4. In section 5 we will draw conclusions from this work and present our ideas for future work.

2 Domain Description

Our study is based on a setting proposed by Sen [11], called the Package Delivery Domain. This multi-participant setting was originally used to study the effects of reciprocity in team formation comprising solely of agents. We expanded the setting to support a negotiation protocol that also allows for individuals to renege on their commitments. This new setting involves multiple participants of varying capabilities who have the possibility to form teams in order to deliver packages to a central depot location. In our setting, we introduce two types of packages: small packages and large packages. Small packages may be delivered by individuals without the assistance of others, large packages can only be delivered by a team of participants with appropriate capabilities. Whether a participant has the appropriate capabilities depends on the location of that package. The utility awarded to individuals for successfully delivering small packages is low and constant. The utility awarded to teams for successfully delivering large packages is high, and increases with respect to the number of team members. Table 1 summarizes the key elements of the Package Delivery Domain.

Figure 1: Snapshot of the Main Board Panel for Package Delivery Domain

2.1 Implementation using Colored Trails

We implemented the Package Delivery Domain using the Colored Trails (CT) [3] framework. CT is a tool used for empirical studies of human-agent decision making. The CT game we designed is played by six participants on a 11x11 board of colored squares. One central square on the board is designated as the goal depot. Each participant is represented by an icon on the board initially located at a random position on the board (the depot location and package locations excluded). Each icon is assigned a color from the same palette as the squares on the board. Each color in our palette is represented by both a human and an agent participant. A snapshot of one of the boards used in our study is shown in Figure 1. Figure 1 also shows three of the six participants in the game: a blue 'me' icon, representing the location of the participant viewing this board; a red agent icon, located near the bottom-right corner of the board, and a green human icon, located one square to the right and two squares up from the goal depot. The current score of the 'me' participant is displayed at the bottom of the main board panel.

Participants can move freely on the board, but not diagonally. Also shown in the Figure are packages dispersed over the board. We colored small packages white, and large packages brown. At any given point there were twelve small packages and six large packages located at random positions on the board, other than the depot, with the restriction that large packages are always placed at a distance of at least two squares from the depot. If a package is delivered, another one is automatically generated and positioned at a new location on the board.

2.1.1 Forming Teams and Delivering Packages

The aim of the game is to pick up and deliver packages to the goal depot. Delivering small packages by individual participants requires that they would move across the board to position their icon on the intended package and then move towards the goal depot. Delivering larger packages requires individual actors to form teams by inviting one or two other participants and jointly delivering the package to the depot. In this case, it was required that the color of each team member (i) was different than the color of all other team members, (ii) matched at least one square in the path from the position of the large package to the goal.

The protocol for forming teams requires that participants agree to collaborate with the other team members. To do so, one of the participants, called the *team initiator*, invites others by proposing a split of the reward associated with the successful delivery of the package to each participant in the team. An invited participant can either accept or decline the invitation. This negotiation protocol may considered as an iterated ultimatum game [4]. Once a participant accepts the split of the reward, that participant automatically joins the team.

Participants were provided with a cognitive aid tool, showing their current team affiliation as well as the history of their past teams. An example is shown in Figure 2. The figure shows the offers made by and made to the red 'me'-player. Once every invited participant has joined the team, they must position their icons on the square with the large package where the initiator is situated. At this point the team automatically delivers the large package. At the point of delivery, the rewards are distributed according to the agreed upon splits.

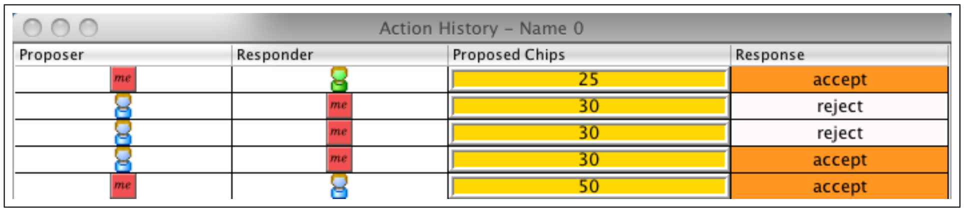

Figure 2: Snapshot of the window displaying the history of offers of one player.

Any member in the team can choose to defect from its contract and dissolve the team. Team members can defect by accepting outside offers that are proposed by non-team participants. In addition, team initiators can also defect by moving their icons to a different position from the one in which the large package is situated. If anyone chooses to defect, the entire team fails and none of its members receive any reward.

2.1.2 Scoring and Motivation

Each small package delivered to the goal depot yields a reward of 3 points to the individual participant. A two-member team that delivers its package successfully incurs a reward of 60 points to split between all team members, and a three-member team incurs a reward of 180 points. These values were set after several pilot studies and were meant to incentivize participants to form teams, despite the increase in waiting time and risk of defection that comes with creating one.

When the rewards are distributed among all members in a completely equal way, the average score for each member of a two-player team is 30 points, whereas the average score for each member of a three-player teams is 60 points; this is significantly more than the average relative score for two-player teams.

This setting is particularly well suited to study group decision-making in fast-paced domains because it requires that actors manage their conflicting intentions between acting selfishly and incurring a short term benefit (e.g., defecting from a team by accepting a more lucrative offer) and acting cooperatively for the long term gain (e.g., remaining committed to the team and establishing a positive trust relationship). Also, it is highly interactive in that actors in the domain need to simultaneously reason about different types of decisions (e.g., a team member can receive an outside offer while it is negotiating the terms of a different contract with another participant). Furthermore, the domain is characterized by uncertainty at several levels: about the environment (e.g., the duration of a game, and how packages will be distributed) and about other's decision-making processes (e.g., how others decide whether to defect from their commitments to the team, and how much they offer others to join their team).

3 Empirical Methodology

Our experiment involved a total of 90 group games, played by 18 subjects from diverse socio-economic backgrounds. Although the number of of subjects is small, the number of played games provide a significant amount of data. 44% of the subjects were male. 50% of the subjects were younger than 25, 44% were between 25-29 years old and 6% were between 30-34 years old. The majority (72%) of the subjects were students. Subjects went through an identical 45-minute tutorial of the game and needed to pass a comprehension quiz to participate in the study. Subjects were not allowed to communicate and could not see each others' console. Each subject participated in a series of CT rounds in which the board configuration as well the identity of the other participants were varied. The duration of each round was between 4 and 10 minutes. Subjects were monetarily compensated according to their total performance in the rounds they played. Our subjects were not told the duration of each round to ensure that their behavior would not be influenced by time. Each subject participated in 5 rounds.

Throughout the study all participants were human but some people appeared to be agents to other participants. This fact was not revealed to the subjects throughout of the study.[1] There were several benefits to this deception. First, it isolated the effects concerning the type of subject (whether human or agent) on people's behavior. Had we used actual agents it would have been impossible to distinguish between those effects relating to the type of participant from those relating to the strategies used by the agents. By having humans play the role of agents, we could attribute differences in behavior solely to the way people relate to

[1] The deception was approved by the Institutional Review Board of the academic institution sponsoring the study.

Table 2: Statistics for formed and successful teams

	formed	successful	
	frequency	frequency	% of formed
2-member teams	122	83	68%
3-member teams	205	114	56%

different participant types. Second, it allowed the data we collected to be used as a baseline for evaluating decision-making strategies to be used by agents in future studies. We varied the identity of participants that were presented as agents at each round of the study. All participants appeared as human to themselves, but in any given round it was possible for a participant to appear as a human to one participant, and as an agent to another participant.

4 Results & Discussion

We first present results summarizing general performance, which varied significantly across participants. While the mean score was 565 points, the standard deviation was 300 points, and participants earned as many as 1498 and as few as 153 points. We found that joint actions (forming and joining teams and delivering large packages) as well as individual actions (delivering small packages) were both significant predictors of performance (linear regression $F(2, 69) = 105.71, r^2 = 0.7539, p < 0.0001$). However, the successful delivery of large packages was a significantly higher predictor of performance (t value 12.93, $p < 0.0001$) than delivering small packages (t value 3.63, $p < 0.0001$). This confirms that subjects understood the rules of the game, which is a necessary "sanity check" in light of our relatively complex setting. The next sections analyze team formation and intention reconciliation in terms of social factors.

4.1 Team Formation and Team Stability

We distinguish between several events related to team formation and decision-making: we say a team is *formed* if all of its members have agreed with the initiator on the distribution of the potential reward of delivering a package. A team is considered *successful* if it delivered its package to the depot, and a team has *failed* if at least one of its members defected before the package was delivered.

Table 2 lists the number of teams formed by participants, and the number of times that those teams were successful. As shown by the Table, there were significantly more three-member teams (205) formed than two-member teams (122) (goodness of fit test $p < 0.0001$). Forming larger teams involved a higher risk than forming smaller teams, because there were more team members in larger teams that could choose to defect from their respective agreements. Another source of risk was time. The average time required for participants to (i) negotiate over collaboration, (ii) form three-member teams and (iii) complete their joint task was about three minutes, significantly longer than the one minute it took to form and complete two-member teams. This is because the team initiator had to negotiate separately with each participant. It is thus striking that participants were more likely to form larger teams, despite the additional risk factor. The questionnaire shows that the difference in payoff was a strong motivation for players to create 3-player teams.

Interestingly, there was no significant difference in defection rates between three- and two-member teams. The average likelihood of defection for participants in three-member teams was 16%, while the average likelihood of defection for participants in two-member teams was 15%. However, the data shows that two-member teams were more robust: Table 2 shows that the percentage of successful two-member teams was 68% of the formed teams, which was significantly higher than the percentage of successful three-member teams (56%) ($\chi^2(N = 1,304) = 11.8, p = 0.0001$). The reason is that defection by a single member will dissolve a team, and larger teams have more members. Therefore, although participants were not more loyal to smaller teams than they were to larger teams, smaller teams were more likely to succeed.

4.2 Intention Reconciliation

We hypothesized that two factors affected participants' decisions whether to defect from their current teams by accepting outside offers. First, that outside offers that participants accepted were significantly higher than

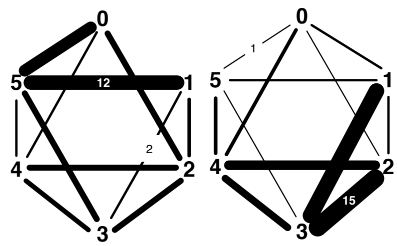

Figure 3: Examples of social graphs describing trust relationships among participants in two games

the reward allocated to participants in their current team. Second, that participants established a positive relationship with each other leading them to prefer to interact with some participants over others.

Analysis of the data reveals that both of these factors significantly affected participants' decisions whether to defect from their team, but they varied in magnitude. Outside offers were on average 6 points more beneficial for team members than the reward allocated to them by their current team ($t(52) = 1.04, p < 0.05$). Although this gain in benefit is small, we note that participants could not see the rewards associated with non-team members and that this number also includes outside offers that were not accepted.

We also analyzed the tendency of participants to prefer to interact with participants they have interacted with successfully in the past. Given the high degree of uncertainty and incomplete information associated with the setting, it was infeasible for participants to compute the expected reward of teaming up with any subset of individuals. Hence, there was no *a priori* reason for participants to prefer one team configuration over the other. Despite this fact, participants showed a preference to interact with those they successfully interacted with before. Our results show that 56% of all successful three-member teams and 42% of all successful two-member teams consisted of team configurations of members that had interacted successfully in the past.

To provide a finer grained measure of this relationship, we defined the *trust value* between any two participants as the number of times they cooperated in the past in any team configuration. Following recent work in multi-agent systems, we use this notion as a measure of the likelihood of future interaction between agents that have interacted successfully in the past (cf. [2]). Figure 3 shows a graphical representation of the trust relationships that were formed in two of the games. Nodes in the graph represent participants, and edges connect participants who agreed to be teammates in past interactions. Note that a complete graph (with all nodes connected) is not possible because participants of the same color could not be teammates in our domain. Edges are labeled with trust values for each relationship. Thicker edges represent stronger relationships, meaning that participants interacted more frequently. As shown by the Figure, diverse relationships were established, and a disproportionate number of participants joined the same team multiple times. This pattern repeated itself for the other games in our study, and played a role in participants' decisions whether to defect. In all, there was a positive and significant correlation of 0.29 between (i) the trust value between team initiators and their team members, and (ii) the trust value between those team members and non-team members who made outside offers to the team members.

Having established that positive interaction builds trust relationships in our domain, we examined whether negative interaction led to punishment. We hypothesized that participants that were more likely to defect would suffer in performance, because former team members would be less likely to invite them to join future teams, or to agree to join future teams initiated by past defectors. However, we did not find that defections were a significant predictor of performance. There are two possible explanations for this. First, defectors chose offers that were more beneficial to them than the reward allocated to them in their original team, and this was enough to offset the losses incurred by others' negative reciprocity. Second, participants could not observe defections in other teams, and since our game was not designed as a reputation game, participants could not communicate information about the reliability of other participants.

4.3 The Effect of Participant Type

In this section we study whether the nature of the opponent affected the way participants made decisions. Remember that all participants were human in our setting, but some of them appeared as agents to other participants. The purpose of this was to control any effects on behavior relating to participant type. We focused the analysis on the extent to which participants engaged in fair behavior given their perceived type of partner. To this end, we defined a measure of fairness in our scenario that depended on the relative size

Table 3: Fairness measure of offers made to humans vs. agents and in 2- vs. 3-member teams

	Humans / Agents	2-member/3-member
Fairness	94% / 82%	82%/99%

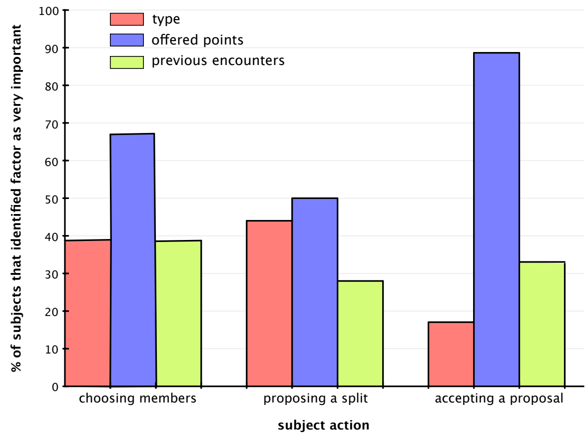

Figure 4: Factors of importance for subjects' decisions according to post-study questionnaire

of the split offered by team initiators to their respective team members. For example, a 100% fair offer to a participant in a two-member team (with a total reward of 60 points) was 30 points, and a 50% fair offer was 15 points. Similarly, a 100% fair offer to a participants in a three-member team (with a total reward of 180 points) was 60 points, and a 50% fair offer was 30 points. The left-hand column of Table 3 presents the average fairness of offers made by team initiators to potential members that they perceived to be an agent or a human. As shown by Table 3, the average fairness of offers made to humans (94%) was significantly higher than the average fairness of offers made to agents (83%) (combined t-test $t(692) = 1.45, p < 0.0001$). However, there was no significant difference between the percentage of accepted offers from human and agent initiators. For both initiator types, offers averaging below 83% fair were mostly rejected, and offers averaging above 91% were mostly accepted. Lastly, there was no difference in the rate of defection from agent- versus human-led teams.

To summarize, people were more likely to be generous to humans than to agents when forming teams, but they did not discriminate against agents when inviting participants to join teams. Also, there was no difference in people's commitment to teams led by humans and agents. These results are surprising given that in ultimatum-game type settings of previous studies people were willing to accept lower offers from agents than from people [9, 1]. We hypothesized that the reason for this discrepancy is that the ultimatum game is a one-shot setting, and refusing offers incurred zero benefit. In contrast, players had more opportunities to incur rewards in future interactions in our setting, and thus saw fit to decline offers they did not see as fair.

The right-hand side of Table 3 presents the average fairness of offers made by team initiators to potential members in a two-member and three-member team. Offers made for members of a two-player team were significantly more fair (99%) than for members of a three-player team (83%) (combined t-test $t(690) = 8.90, p < 0.001$). A possible explanation for this is the significant difference in payoff that participants could receive for two- or three-player teams. Initiators of three-player teams could offer less than a fair split and still provide significantly higher payoff to the member than this member would obtain in a fair split from a two-player team. Thus, initiators of three-player teams could be more selfish, while still making offers that were "good enough" to be accepted by the team participants.

We conclude this section with a partial description of the questionnaire filled out by subjects immediately following the study. As shown in Figure 4, the type of participant was a very popular factor (44%) of people's decision of how to propose splits. In contrast, the size of the split was by far the most popular explanation of people's decision whether to join teams (89%) and to choose members for a team (68%). These reports are in line with the statistical analysis described earlier, and confirm that social factors (participant type, fairness, and to a lesser extent, trust relationships[2]) drive human behavior in fast-paced domains.

[2]This we attribute to the relative difficulty of keeping track of past encounters, despite the use of the cognitive aid.

5 Conclusions & Future Work

As any social entity, agents often need to collaborate with humans and other agents in order to achieve their goals. In this paper, we have addressed some of the limitations of existing teamwork and formation approaches when applied to mixed teams. We have presented an empirical study which examines how human-agent teams are formed in a fast-paced domain. The main contribution of this paper is the empirical study of the complex interplay of multiple social factors such as trust and fairness and the presence of different participants in a dynamic setting, where decisions quickly follow each other.

This research makes several important contributions to both behavioral and computational studies. First of all, it shows that people are as loyal and committing to agents as they are to humans and that they are as likely to join agent-led teams as they are to join human-led teams. This is an important observation which suggest that people have no problem working alongside autonomous systems. What is more, effective teamwork between agents and humans can be agent-initiated since people will carry through their commitments with their agents partners as much as they would with people. These conclusions can be used on the design of collaboration systems for search-and-rescue, decision-support systems and personal assistants for e.g. space applications. Second, our results have shown that people tend to discriminate agents by offering them less than humans. This implies that for the purpose of designing agents that are able to interact and cooperate in an intelligent way on behalf of their users, the agents need to appear and behave in a natural and 'humanly' fashion. Third, our data reveals that players were likely to interact with those they successfully interacted with before. This has implications for the design of systems that interact with people during long periods of time, such as companions and game characters, as it gives an indication that people will expect agents to have a memory of past experiences. However, more research is needed to confirm this observation.

In future work, we expect that a similar study in an e-commerce setting will show that agents who are perceived as humans will perform better than agents of which it is known that they are computerized.

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