Modeling User Perception of Interaction Opportunities in Collaborative Human-Computer Settings

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Introduction

Interruptions are an important part of effective collaborative work, because different agents in a team often possess information required by others. This need to get information from another agent arises in mixed human-computer teams as well as in homogeneous computer-agent environments. For example, a (human) driver will see changes in weather conditions that may affect route selection while an automated navigation system without sensors does not. The navigation system may determine that such information would help it identify the best route. It is crucial to time interruptions appropriately, because they are inherently disruptive. Efficient interruption timing improves task performance as well as emotional state and awareness of the user, while decreasing the negative effects of interruption (Adamczyk & Bailey 2004).

A key aspect in reasoning about initiating interruptions in collaborative settings is the ability to accurately estimate the costs and benefits associated with the interruption so that the outcome of the interruption positively affects task outcome. Cost estimation has been investigated in prior work on interruption management (Horvitz & Apacible 2003), but this work presumes a benefit to the user of having information the computer system can provide. The benefits of interruption have been studied in the adjustable-autonomy literature, but that work focuses on when to turn control over to a person (Tambe *et al.* 2006). Few models have combined these two aspects into an integrated decision making mechanism (Fleming & Cohen 2001), and none have done so in the kinds of fast-paced domains we consider, i.e., domains in which agents are distributed, conditions may be rapidly changing, actions occur at a fast pace, and decisions must be made within tightly constrained time frames. Furthermore, almost no attention has been paid to the possible discrepancy between a computer agent's calculation of the utility of the interruption and a person's estimation of the usefulness of the interruption. The failure to see the value of an interruption may lead a person to reject the interruption, thus missing an opportunity to improve overall team performance and turning the interruption into an unnecessary disturbance.

Our research proposes a new model for interruption management. This model aims to help to maximize the efficiency of collaboration between an agent and a person by better estimating interruption outcome and by taking into account the possible mismatch between the computer's calculation of utility and the person's perception of it. In particular, it focuses on determining the factors that influence a person's perception of an interruption, and consequently the overall tendency to accept or reject it, when that interruption is generated by a computer system. The results will enable the design of more efficient interfaces, ones for which the likelihood is higher that valuable interruptions will be accepted by the user. This research is part of the effort for developing a coordination autonomy module in DARPA's Coordinators project in which an agent needs to reason about interrupting a user for obtaining information that can influence its ability to solve a scheduling problem.

To investigate the interruption management problem empirically, we developed a new, abstract game using the Colored Trails (CT) infrastructure which has been used previously as a research test-bed for a variety of decision-making problems (Grosz *et al.* 2004). Our framework is abstract enough to enable us to focus on investigating the interruption problem without the specification overhead of real world domains. At the same time, it is sufficiently interesting for human participants to play that it provides a good environment in which to investigate human-computer interaction.

Modeling Interruptions

The CT game we defined involves two players, one controlled by a computer agent and the other by a person, located on the CT board. Players are allowed to move one step at a turn in one of four directions. They aim to reach their individual goals as quickly as possible. When a player reaches the assigned goal, this player and the player's goal are randomly relocated on the board, and another round of play starts. (This new round is the analogue of being assigned a new task.) The dynamically changing nature of the real world is mimicked by having the goals move stochastically with a probability determined by a Gaussian function with a center at the current position of the goal.

The remainder of this paper describes an initial investigation which considers a collaborative setting in which the person has complete information—including information from which the agent can benefit —and the agent has incomplete information.[1] In particular, the person has complete information about both players and their goals, whereas the agent lacks current information about its goal's position (but knows its position and the position of both the person and person's goal). The agent needs to initiate interactions with the user to learn its actual goal position, because its information about the position diminishes over time. We model the cost of interruption as the loss of the opportunity to move for one turn. At the beginning of each turn, the agent decides whether to interrupt the user or not. The person is free to accept or reject an interruption request. If the person responds positively to an interruption request, the agent receives the current position of its goal and both players are prohibited from moving for this turn. The game continues until a certain number of turns are played.

To model a collaboration, the players share a common scoring function S,

$$S = S_P + S_A \text{ and } S_i = \sum_k (s - h_k)$$

where S_A and S_P denote the agent's and the person's accumulated (individual) points, respectively, s is the number of points given for reaching a goal, h_k is the number of moves it takes for the player to get to the kth goal, and the sum is over all goals that have been reached by player i. The objective of players is to maximize the shared scoring function S. The person has an incentive to accept interruption requests, because overall success, as represented by the scoring function, depends on the agent's ability to reach its goal.

The agent interrupts the user when the expected outcome of interruption (EOI) is estimated to be beneficial (positive). The EOI is the difference between the expected outcome (EO) of the game when there is an interruption and the EO when no such interruption takes place. This calculation requires deriving joint policies for the collaborative group of agent and user. This problem may be modeled as a Decentralized POMDP (Dec-POMDP). However, the complexity of the solution is *NEXP-complete*.[2] As a result, our approach is to estimate the EOI by combining agent-sided and person-sided estimates of interruption outcomes as shown in the equations below, where I indicates Interruption, NI indicates No Interruption, and EU indicates Expected Utility:

$$EOI = EOI_P + EOI_A$$
$$EOI_P = EU_P^I - EU_P^{NI} \text{ and } EOI_A = EU_A^I - EU_A^{NI}$$

The person-side estimate may be modeled by a Markov Decision Process (MDP), because the person is able to observe the complete state of the world. ExpectiMax is used to calculate EU_P for the current state of the world, which is represented by person-player position p, goal position g and current turn h. Given that B indicates the set of possible board positions and $MP(g', p, g)$ is the probability of a goal move from position g to g' with player position p,

$$EU_P^{NI} = EU_P(p, g, h)$$
$$EU_P^I = \sum_{g' \in B} MP(g', p, g) \times EU_P(p, g', h+1).$$

To model the agent-side estimate requires a Partially Observable MDP (POMDP), because the agent does not have complete information about the state of the world. The current state of the game is represented by agent-player position p; belief state b, which is a probability distribution over the possible goal positions; and current turn h. After each turn, b is updated to b' with State Estimator (SE).

$$b'(c' \in B) = SE(c') = \sum_{c \in B} b(c) \times MP(c', p, c)$$
$$EU_A^{NI} = EU_A(p, b, h) \text{ and } EU_A^I = EU_A(p, b', h+1)$$

Experimental Setting

We are currently running experiments and collecting data from participants playing this CT game in a lab setting. To evaluate the agent's interruption decision making performance, we simulate three homogeneous agent settings and compare their results with the results obtained in human-agent experiments. The benchmark settings are composed of two (fully rational) computer agents with different capabilities playing CT: (1) both agents have complete information; (2) one agent has incomplete information, but is able to interrupt the other agent; and (3) one agent has incomplete information and is not able to interrupt the other.

In the second set of experiments with human and computer agent players, we use hand-crafted interruptions generated by the computer agent, where we vary a wide range of controlled parameters (e.g., the computational complexity associated with calculating the costs and gains, the magnitude of the net benefit (EOI), the type of the collaborator). We are thus able to identify the subset of factors the agent needs to focus on when applying learning and profiling techniques for better predicting specific users' tendency to accept future interactions. The findings have an immediate benefit for systems like Coordinators as we can facilitate the agent's interruption-related decision making by supplying it with a set of dynamic thresholds for initiating interruption.

Conclusion and Future Work

In this paper, we described an experimental design and a computational framework for exploring an integrated interruption model in collaborative settings and investigating the way people perceive the effectiveness of interruption. Our abstract model can be generalized to real world applications such as email assistance by replacing the simple cost and utility functions with application specific functions. In future work, we aim to model the way people perceive the outcome of an interruption and combine this model with existing interruption management systems to improve the efficiency of collaboration in human-computer settings.

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[1] This initial experimental setting provides a baseline for assessing the basic influences different problem factors have on a user's determination of an interruption's usefulness. Future work will vary the allocation of information.

[2] Comprehensive analyses of the problem, including MDP, POMDP, Dec-POMDP approaches for capturing the value of the interaction may be found in a longer paper (Kamar & Grosz 2007).

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