Using Computer Simulation to Compare Two Models of Mixed-Initiative

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Abstract

In this paper, we use computer simulation to better understand mixed-initiative dialogues. We compare two models of mixed-initiative: unrestricted initiative, where either participant can take over control at any point; and restricted initiative where one participant keeps control and the other plays a secondary role, but greater than what single-initiative allows. We find that restricted initiative results in similar solution quality as unrestricted, less communication effort, and similar or less reasoning effort. These results agree with our empirical studies on human-human dialogues, in which we find that participants seem to follow the restricted initiative model.

1. Introduction

Current dialogue systems tend to be single-initiative, where either the user or the system directs the flow of the conversation. The speaker who has control asks questions, makes statements, while the other just answers questions. The usefulness of such systems depends on how structured the task is. For collaborative tasks, single-initiative will not be sufficient, as it will hinder the participants' ability to accomplish the task.

The aim of mixed-initiative dialogue systems is to allow both participants to more fully participate in the conversation. However, now we need to determine when it is expected or appropriate for the system to show initiative, and when it should let the user take the lead.

A number of theories have been proposed for how initiative is managed, such as [1, 2, 3, 4, 5]. Whittaker and Stenton [1] proposed that initiative does not simply bounce back and forth; rather, after a person shows initiative, they tend to keep on showing initiative without intervening initiative by the other speaker. We refer to their model as *unrestricted initiative* because both speakers play the same role in showing initiative.

In previous work, we studied human-human dialogues and proposed that initiative is subservient to discourse structure: the speaker who initiates a discourse segment, say A, is the one who has control during the entirety of the segment [6]. This is not single initiative, as the other speaker, B, is still free to show initiative. However, the initiative is just fleeting, and returns to A after B finishes the utterance. In other words, B can show initiative but does not take over control. Inside of A's discourse segment, B (or A) is free to start a subsegment. Once the subsegment is over, control returns to A. We call this theory *restricted initiative*.

The problem with our previous work of studying human-human dialogues is that we can only observe what did happen. It is hard to determine why it happened, and hence it is difficult to be sure which model of initiative people do follow or are capable of following. A second alternative is to run human-computer studies and compare user satisfaction with a computer system employing the unrestricted initiative with one employing restricted initiative. However, spoken language technology is not advanced enough to test such systems; in fact, with current technology, single-initiative systems are found to perform better than mixed-initiative ones [7]. A third alternative is to employ a Wizard-of-Oz approach, in which users think they are talking to a computer system, when in reality they are talking to another person, playing the role of the system. However, the success of this approach depends heavily on the experience of the wizard and it is expensive to collect enough data to get statistically reliable results. Furthermore, we cannot test models that are unnatural for a person, and so cannot investigate how well alternative unnatural strategies would really work, as we would even have to train the user.

In this paper, we use computer simulation to understand the characteristics of different initiative strategies. We compare four strategies, two based on unrestricted initiative and two based on restricted initiative. We compare the strategies in terms of communication effort, reasoning effort, and solution quality.

2. Simulation Setup

In this section, we describe the domain task that the simulated speakers must accomplish. We also describe their communication language and their reasoning ability.

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2.1. Domain Task

We adopted the Design-World task used by Walker [8]. This task involves two agents, A and B, carrying out a dialogue to arrange furniture in a two-room house. A furniture item has three attributes: type (e.g. sofa, bed, table), color (e.g. green, white), and value (positive numbers). If an item is moved into a room, its value is added to the overall score. The goal is to get the highest score by having four furniture items in each room. Each agent initially knows about a subset of the furniture.

We made the following modifications. First, we simplified the task to a single room with five furniture items. Second, each agent knows about all of the furniture items. Third, each agent has private preferences, which the other agent initially does not know. We use six types of preferences. Below are examples of each type.

- *There should be a bed in the room.*
- *A TV is not allowed in the room.*
- *If the room has a green bed, it should have a red chair.*
- *The room should not have both a table and a bed.*
- *If a desk is not in the room, a table should be.*
- *If the room has a bed, the bed should be red.*

Each preference has a value between 1 and 20. If a preference is violated, its value is subtracted from the overall score.

2.2. Communication Language

Similar to Walker [8], agents communicate using four different speech acts. The schemas are given below.

- *Propose move_in(Item)/move_out(Item)/nochange*
- *Inform have(Preference)*
- *Accept*
- *Reject*

We assume both agents understand each other and thus we do not use an acknowledge speech act.

2.3. Agent Reasoning

An agent's knowledge includes three types of information: all furniture items, which items have been moved in, its preferences and those of the other agent that have been communicated, which are now mutual beliefs. Finding the best solution is a NP complete problem. To reduce the cost of computation, agents employ a greedy algorithm in deciding which items to move in. As we will show in Table 1, the greedy algorithm obtains a near optimal solution.

Agents will only reason about the next item to move in. For each available item , the agent forms a plan with the item plus the items already in the room and calls the function calc_plan_value(PartialPlan). This returns the score of the plan, which is the sum of the individual items subtracting the sum of all preferences violated. The agent then chooses the item with the highest score.

3. Dialogue Strategies

The agents employ four different dialogue strategies, two based on unrestricted initiative and two based on restricted initiative. In the strategies based on unrestricted initiative, the agents converse until they agree on a set of furniture items, which they both think are optimal. This is done by the first agent, A, proposing an item or items, and the other agent, B, comparing the proposal to what it thinks is optimal. If there is a difference, B then informs A of each of its *violated preferences*, which i) lower the score of A's proposal but not B's and ii) are not already known by A. As B now has control, B proposes the plan that it thinks is optimal, and the cycle repeats. Unlike Walker's model [8], agents never forget what the other agent tells it. These strategies are guaranteed to halt with agreement.

The two strategies based on restricted initiative are very similar to the ones described above. The difference is that B, after it informs A of the *violated preferences*, does not take over control. Hence, B does not propose a solution next. Rather, the cycle continues with A formulating a new plan and communicating it to B.

3.1. Item Mode Unrestricted

In this mode, A first determines the best item to move in and proposes it. B compares A's item with the one that B would have proposed. If both have the same score (from B's beliefs), B accepts it, and A continues with the next item. Otherwise, B rejects A's proposal. B then informs A of the *violated preferences*, followed by proposing its item to A. A then acts as the evaluating agent. Once an item is accepted, it cannot be retracted. The dialogue ends after 5 items have been accepted.

3.2. Plan Mode Unrestricted

This protocol is illustrated in Figure 1. A first determines all five items to move in. It does this by first finding the first item, and assuming that it is accepted, then finding the second item, etc. Once it has all five, A proposes each of the five items to B. B then compares A's plan to the plan that B would have proposed. If both have the same score (from B's beliefs), B accepts A's proposal, and the dialogue would end. Otherwise, B rejects A's plan, informs A of the *violated preferences*, and then proposes its solution to A. A then acts as the evaluating agent.

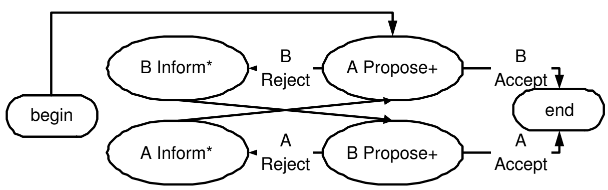

Figure 1: Plan Mode Unrestricted

In proposing a plan, if at least three items differ from the previous plan, the agent will propose each item. Otherwise, the agent will propose to move out the different items and move in the replacements.

3.3. Item Mode Restricted

This mode is similar to the unrestricted version in Section 3.1. A proposes an item. B compares this item against the one that it would have proposed. If B's item has a higher score than A's, B informs A of all of the *violated preferences*. As B does not have control, B does not counter-propose. Instead, A uses its new beliefs to recompute a new item. Note that if B does not have any preferences of which it can inform A, then B must accept A's proposal, and A then proposes the next item.

This mode is very different from the unrestricted one. A and B play very different roles. B relies on A to form the best plan, and assists A in doing this by informing A of any preferences that it thinks are relevant. As A never informs B of its preferences, B cannot double check A's solution.

3.4. Plan Mode Restricted

This protocol is illustrated in Figure 2. The dialogue starts by A informing B of the five items it wants to move in. B then compares the score of A's plan with its plan (note that B's plan never changes as B is never informed of any of A's preferences). If A's plan is as good as B's or B does not have any *violated preferences*, B accepts and the dialogue ends. Otherwise, B informs A of all *violated preferences* to A. A then uses the new beliefs to compute a new solution. Just as in Section 3.2, if A is changing two or fewer items in the plan, it proposes to move out the changed items and move in the replacements. It could be the case that A wants to propose the same plan. In this case, it issues just a single proposal of *nochange*.

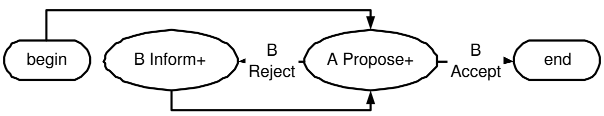

Figure 2: Plan Mode Restricted

4. Experiment

We examine the four dialogue strategies under different simulation parameter settings. The parameters include the overall number of items to choose from (I_o), the number of items to move in (I_m), and the number of preferences initially known by Agent A and Agent B (P_A and P_B). In our experiment, we fixed I_m at 5, P_A and P_B both at 40, and varied I_o among 10, 20, and 40. Here, I_o reflects the complexity of the task.

For each parameter setting, we randomly generated 100 sets of items and preferences. Table 1 shows the optimal solution quality for these 100 sets (using a global search) and the solution quality as found by the greedy reasoning procedure of our agents, given all of the preferences. The greedy algorithm returns a solution that is close to optimal.

Table 1: The mean best-plan quality

I_o	10	20	40
Optimal Solution	-174	-137.6	-110.4
Greedy Search	-174.71	-138.1	N/A

Each of the four strategies was run on these 100 sets of items and preferences, for each parameter setting. We measured the solution quality, the communication effort and the reasoning effort for each simulated dialogue. Solution quality is the value of the final plan. Reasoning effort is approximated by the number of times the function calc_plan_value(PartialPlan) is called (see Section 2.3). Communication effort is the number of speech acts in the dialogue. Because different speech act might have different cost, we report the number for each type of speech act.

5. Results

5.1. Solution Quality

Table 2 presents the mean solution quality of the 100 simulated dialogues for each parameter setting and each strategy. The result shows that the solution quality is not significantly affected by initiative style or by whether plan or item mode is used.

Table 2: Mean Solution Quality

I_o	10	20	40
Item Mode Unrestricted	-175.9	-139.7	-112.4
Item Mode Restricted	-175.5	-140.8	-113.6
Plan Mode Unrestricted	-175.6	-138.9	-112.4
Plan Mode Restricted	-175.6	-139.2	-112.6

5.2. Reasoning Effort

Figure 3 shows the reasoning effort for each strategy under the different parameter settings. When agents are reasoning under item mode, both agents spend almost the same effort in reasoning in unrestricted initiative as they do in restricted initiative. However, when the agents are in plan mode, Agent B exerts a lot less reasoning effort for restricted initiative while A spends about the same.

5.3. Communication Effort

Table 3 reports the mean communication effort of the 100 simulated dialogues for each parameter setting and for

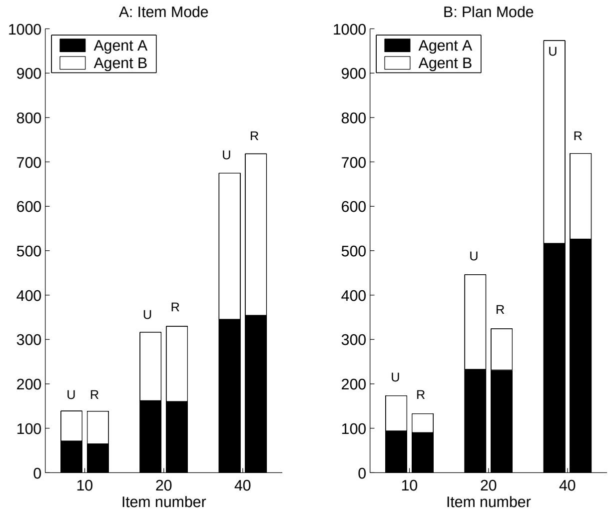

Figure 3: Reasoning effort

each strategy. We report the total number of speech acts, as well as the number of each type, for both speaker A and speaker B. In restricted initiative, B does not make any proposals and A does not make any informs, rejects or accepts; hence these entries are marked with a dash. From the table, we see that restricted initiative requires a lot less communication effort, both in item and plan modes. A lot of the savings is due to A not informing B of its preferences. Surprisingly, we also see fewer overall proposals being made, but with still the same solution quality as shown in Table 2.

Table 3: Communication effort

		Propose		Inform		Reject		Accept	
	Total	A	B	A	B	A	B	A	B
I_o=10									
Item Unrestricted	31.0	5.8	5.1	4.5	4.8	2.7	3.2	2.4	2.6
Item Restricted	21.3	8.0	-	-	5.3	-	3.0	-	5.0
Plan Unrestricted	21.5	7.5	4.4	2.4	4.0	0.9	1.3	0.4	0.6
Plan Restricted	14.6	8.2	-	-	4.1	-	1.3	-	1.0
I_o=20									
Item Unrestricted	36.4	6.4	5.5	6.0	6.7	3.2	3.7	2.3	2.7
Item Restricted	24.7	8.8	-	-	7.0	-	3.8	-	5.0
Plan Unrestricted	30.5	9.5	6.2	4.5	6.5	1.3	1.6	0.2	0.8
Plan Restricted	18.9	9.8	-	-	6.5	-	1.6	-	1.0
I_o=40									
Item Unrestricted	38.7	6.6	5.9	6.5	7.3	3.5	3.9	2.4	2.6
Item Restricted	26.4	9.3	-	-	7.8	-	4.3	-	5.0
Plan Unrestricted	34.7	9.9	6.8	5.5	8.4	1.4	1.7	0.3	0.7
Plan Restricted	22.8	11.4	-	-	8.6	-	1.8	-	1.0

6. Conclusion

The results above show that when the dialogue participants follow restricted initiative strategy, the dialogue is more efficient, either by saving reasoning effort or communication effort. Note that in restricted initiative, the non-initiator needs to trust the initiator to do the reasoning. According to Grosz and Sidner [9], the goal of a discourse segment is the intention of the initiator. Thus it is reasonable to assume that the initiator is responsible for the goal unless the initiator delegates it to the non-initiator by making a request. This simulation result is consistent with our empirical studies of human-human dialogues [6]: the initiator is indeed responsible for driving a discourse segment towards its purpose, while the non-initiator only shows initiative occasionally. The results of our simulation thus give further evidence for our restricted model of initiative.

Our two dialogue strategies of restricted initiative could be interpreted as also supporting Chu-Carroll and Brown's model of initiative [2], in which they distinguish between dialogue initiative and task initiative. According to their model, agent A always has task initiative, while dialogue initiative keeps alternating between agent A and B. In our work, we plan to make the task complex enough so that it is beneficial for agents to have hierarchical structure to their dialogues. This should allow us to make dialogue strategies that distinguish between our model of initiative and that of Chu-Carroll and Brown's. We also plan to model communication failure and turn-taking issues, and see how these affect initiative strategy.

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