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Peer-reviewed author version

OCTAVIA, Johanna; BEZNOSYK, Anastasiia; CONINX, Karin; QUAX, Peter & LUYTEN, Kris (2011) User Modeling Approaches towards Adaptation of Users' Roles to Improve Group Interaction in Collaborative 3D Games. In: Proceedings of the14th International Conference, HCI International 2011. p. 668-677..

Handle: http://hdl.handle.net/1942/12143

User Modeling Approaches towards Adaptation of Users' Roles to Improve Group Interaction in Collaborative 3D Games

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Abstract. This paper focuses on how adaptation of users' roles based on a collaborative user model can improve group interaction in collaborative 3D games. We aim to provide adaptation for users based on their individual performance and preferences while collaborating in a 3D puzzle game. Four different user modeling approaches are considered to build collaborative user models. Through an experiment, we present the validation of these approaches for two different cases: co-located collaboration and remote collaboration. From the experiment, we learned that the *Minimum total time* approach, which defines the best collaboration as the one that gives the shortest total time in completing the task, works mostly effective in both situations.

Keywords: User modeling, adaptation, collaborative 3D games.

1 Introduction

Collaborative 3D games, where players are immersed into a 3D virtual world and can interact with 3D objects or other players, has gained high popularity due to the increasing interest in virtual communities[1] and Massively Multiplayer Online Role Playing Games (MMORPGs)[2]. However, interacting in such 3D world is not always easy for every user. It is more complex compared to real life situations due to the amount of different 3D interaction techniques and interactive tasks that may not always be intuitive for users. Moreover, usage of special 3D input devices with a high degree of freedom (e.g. 3D SpaceMouse) to navigate and manipulate in 3D environments, can cause extra difficulties for the users. This may hinder user interaction and in the end also influence the group collaboration.

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[1] http://www.secondlife.com
[2] http://www.worldofwarcraft.com

We show the user experience in collaborative 3D games can be significantly enhanced by adapting the means of interaction based on the players' model. A model describes the characteristics as well as the capabilities for an individual player. Notice the former (characteristics) is more static data, while the latter (capabilities) can evolve over time. The differences between players' models will influence the way the players can collaborate. For example, a large variation in the skills of each user in a collaborative game may decrease the group motivation to collaborate. We believe group adaptation based on individual user's performance can provide more enjoyable group interaction, thus improving group collaboration.

In this paper, we present a study that explores user modeling approaches to construct a collaborative user model based on individual user's performance. We investigate the utilization of the collaborative user model for providing possible adaptations in a collaborative game to benefit the group interaction. The type of adaptation investigated is the assignment of users' roles based on individual performance with respect to the 3D devices being used. For this purpose, an experiment is conducted where two users have to collaborate on a 3D puzzle game using different input devices. To validate the proposed approaches, two different cases are investigated: co-located collaboration and remote collaboration.

2 Related Work

The range of user characteristics relevant to game playing such as ability level, style, and preference, can greatly vary between players. Providing adaptation in games can be considered as a way to accommodate these player differences, maintain engagement and eventually enhance the gameplay experience. A substantial amount of research has attempted to incorporate adaptation in games such as the modification of difficulty levels [1], enemy's behavior [2], or graphic elements of the game environment itself [3]. These investigations mainly focus on providing adaptation based on the state of a single player. Adaptation in collaborative games should be based on the information acquired from all players in the collaborative gameplay.

El-Nasr et al. [4] have defined a set of collaboration patterns based on investigation of cooperative games. One of the identified cooperative patterns is *shared goals*, which is used to force a group of players to work together to reach the same goal. Task division between players in a collaborative game becomes important to improve the collaboration and win the game at the end. Little research has investigated ways of improving collaboration through the act of dividing actions or roles between players. Assigning specific roles to players based on their individual performance and preference, can be considered as a form of adaptation in collaborative games that has not yet been much investigated.

To provide such adaptation, a user model plays a significant role as it contains factual information about the user (e.g. interaction patterns, preferences, abilities) that can be useful to determine the adaptation. User modeling in games has been overlooked, yet considered to have much potential to result in practical benefits for computer game players [5]. Several researches have proposed ideas towards user modeling in games [6]. User modeling in games can be carried out by measuring a player's game ability to describe how well he/she is playing the game and what influences his/her play. Modeling of players accurately is considered to be a crucial aspect in realizing an effective adaptive game. Therefore, it is suggested for game developers and researchers to more consciously using user modeling approaches to model players in a game design and development.

3 Proposed User Modeling Approaches

Our work proposes to build a collaborative user model that aims to provide adaptation of task division between players in a collaborative 3D game to improve their group interaction. The type of collaborative game investigated in this study is a puzzle game with the shared goals collaboration pattern [4]. We have developed a collaborative 3D puzzle game to validate the user modeling approaches. This type of game involves two main actions: rotation and translation.

To construct the collaborative user model, several user modeling approaches are explored. In this study, the user model is defined as the combination of action and device that is predicted to give the best group interaction. We refer to this combination of action and device as the so-called role. To illustrate how the constructed user model can be, Figure 1 shows two actions (*Rotation* and *Translation*) and two devices (*SpaceMouse* and *Phantom*), which are combined to build the user model. Hence, four possible combinations of action and device, or four roles, can be formed: *Rotation with SpaceMouse*, *Translation with SpaceMouse*, *Rotation with Phantom* and *Translation with Phantom*, as a component for the collaborative user model. The other component of the user model is the information about which player is assigned which one of these roles. Having this information, the collaborative user model is completely constructed.

Depending on how the best group interaction is defined, four approaches of user modeling are proposed:

(1) **Minimum total time**; the best collaboration is defined as the one which gives the minimum total time in completing the collaborative task. For every pair, the total time is estimated for all possible combinations of action and device and then the combination with the shortest estimated total time is selected. To estimate the total time, for every user, the time to perform each role separately is calculated. Then for all combinations, the total time to perform both roles collaboratively is calculated.

(2) **Exclusion of worst individual performance**; the best collaboration is defined as the one which maximizes the group performance by excluding the worst individual performance of a certain user. For every role, the performance difference between users within the pair is calculated. The maximum difference is used to rule out the worst performance value. In the combination with the worst performance, the user with the lower completion time is assigned with the role that was the worst performance of the other user, who obtained the complementary role.

(3) **Minimum performance gap**; the best collaboration is defined as the one which results in the most equal performance among the users by minimizing the

performance gap between them. For every possible combination, the difference of task completion time between users within the pair is calculated. The combination with the minimum time difference between users is selected as the best combination, which is considered to give the most balanced performance.

(4) **Maximum preference**; the best collaboration is defined as the one which makes the best use of users' preference by assigning the most preferred role to each user. For every possible combination, the total subjective preference rating given by users is calculated. Based on the total ratings, the combination with the maximum value is determined as the best combination.

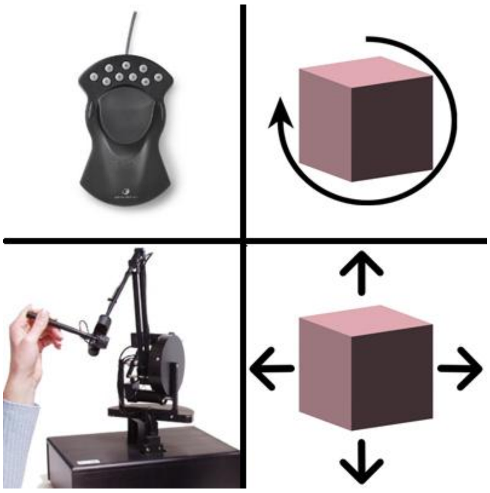


Fig. 1. Actions and devices combined to form the collaborative user model (clockwise from upper right): Rotation, Translation, Phantom, SpaceMouse.

In all approaches, for the best combination found, the total task completion time is estimated as follows. First, for every user, the time to perform each role separately is calculated. Then, the total time to perform both roles collaboratively is calculated. The estimated total times are used to evaluate the efficacy of these four user modeling approaches, which will be validated through an experiment described in the next section. With the experiment, we would also like to investigate how the assignment of users' roles can be adapted for two situations: co-located collaboration and remote collaboration. In the co-located case, we analyze a situation where both devices are available for the users so they can switch devices depending on which device are found to be most suitable for them to operate. However, the collaboration often takes place over distance, so switching devices becomes impossible. Therefore, with the second case, we would like to investigate the situation where the availability of a certain device becomes limited to users due to the remote setting. Based on the findings from these cases, the user modeling approaches are compared to determine which approach suits best for both cases.

4 Experiment

Our work investigates the possibility of providing adaptation within a collaborative virtual environment based on a collaborative user model, which assigns users' roles based on individual performance with respect to the available 3D devices. An experiment was conducted to validate the user modeling approaches proposed for constructing the collaborative user model. Several collaborative user models are developed, based on the goal of collaboration, and applied to two different situations: first, all involved devices are available for both users, and second, only one of the devices is available for each user.

The experiment is based on our previous study [7], which showed no interaction effect between different 3D input devices within a heterogeneous setup when freely collaborating in a virtual environment. In this paper, we explore how different users can align their actions while collaborating using heterogeneous setups. Our experiment limits the type of actions a user can perform in a 3D environment to force them to collaborate for reaching a predefined goal. We use the term role-based collaboration to indicate a user can only perform actions related to the assigned role. We believe that applying the role-based collaboration, which explicitly separates roles between users based on the devices, will improve the group performance compared to the free collaboration, where no roles are explicitly assigned.

4.1 Hypotheses

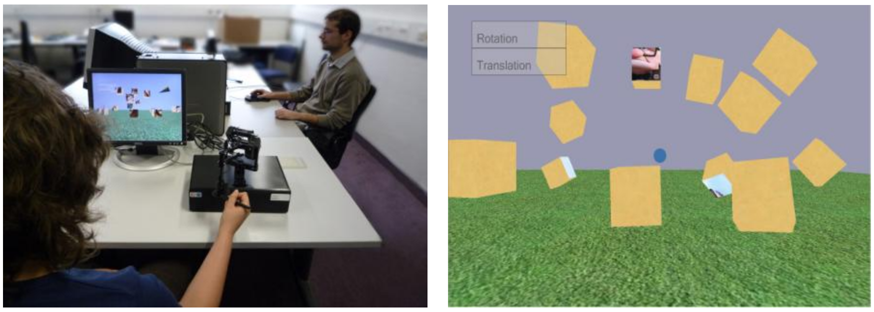
To validate the proposed collaborative user modeling approaches, two hypotheses were suggested: (H1) The modeled task completion time will not differ from the actual[3] time; and (H2) The actual task completion time will be lower than the time during the free collaboration.

4.2 Methods

Twenty unpaid volunteers (16 males and 4 females) were recruited as participants and randomly coupled in pairs for the experiment. The average age of participants was 28 years old, varying from 23 to 34 years old. All participants were people with a computer science background and had little experience working with the devices. All of them were right-handed and used their dominant hand to operate the devices.

The setup described in [7] was used for the experiment. As output devices, two 19" monitors were used. Phantom and SpaceMouse were used as input devices. For both cases, we used the same setup where participants were located in the same room as shown in Figure 2(a), thus co-located. However, participants were seated in such a way that they were not able to see their partner's screen, to simulate a remote setup.

[3] as a result of role-based collaboration



(a) (b)

Fig. 2. Experiment setting: (a) The experiment setup (b) The experimental task.

Participants were asked to collaborate on a 3D puzzle solving task with the shared goal of assembling a complete picture. Each puzzle consists of 12 cubes dispersed in a virtual environment as shown in Figure 2(b). One cube was already placed and served as a visual cue. Part of the picture was presented on one of the cube's sides. Participants were represented by cones with different colors in the virtual environment. Two devices, SpaceMouse and Phantom, were used. Two roles, Rotation and Translation, were defined in the experiment.

The experiment consisted of three independent parts resulting in ten puzzles to be solved. The first part of the experiment corresponded to the session of measuring individual performances. The individual performance data of both participants were gathered and used to build a collaborative user model. Every participant had to complete four separate puzzles individually, which included all possible combinations of roles and devices (see Figure 1). The second part of the experiment consisted of two free collaboration sessions, where no role division was involved so participants were able to rotate and translate as well. The last part of the experiment contained four puzzles to be solved collaboratively, but with applying the division of roles to participants. In this part, roles were assigned complementarily (one participant could only translate, the other rotate).

Throughout the experiment, task completion times were measured and participants were allowed to communicate. After each part of the experiment, participants were asked to fill in a questionnaire about their experience and preference. It took approximately one hour for each pair to complete the whole experiment.

5 Results

In this paper, we focus on improving group interaction in a collaborative 3D puzzle game through the adaptation of users' roles based on a collaborative user model. In Section 3, four approaches have been described to model users' performance in a collaborative setup based on different purposes of collaboration. Using two case studies, we investigate how the proposed approaches can be applied and validated by confirming the aforementioned hypotheses. For this purpose, we analyzed the data using *paired-samples t-tests.* The findings are presented separately for two case studies as follows.

5.1 Case Study 1: Co-located collaboration

In this case study, we investigate the application of the four user modeling approaches in a situation where both devices are available for the users. The two hypotheses formulated in Section 4.1 will be analyzed to validate each approach. Table 1 summarizes the results of the hypotheses analyzed in this first case study.

Effectiveness of collaborative user models. With the first hypothesis, we investigated whether or not the collaborative user models, which were constructed based on the four user modeling approaches, approximate the real performance in a role-based collaboration. Based on this hypothesis, we expect that the estimated task completion times based on the collaborative user models will not differ from the actual times measured from the role-based collaboration.

For every approach, we found that task completion times do not significantly differ across the modeled and actual times, which means that the modeled task completion time does not differ from the actual time measured as a result of role-based collaboration. From this, it can be concluded that **our collaborative user model is a good approximation to the actual performance**. In another way, we can say that all four user modeling approaches proposed in this study can be considered valid to construct collaborative user models.

Effectiveness of role-based collaboration. The second hypothesis demonstrates the potency of role-based collaboration that adaptation of users' roles improves the group interaction and performance. Based on this hypothesis, we expect that the actual task completion times measured during the role-based collaboration will be lower than the times during the free collaboration.

Only the *Minimum total time* approach confirmed that the role-based collaboration to be effective. We found a significant difference between the actual task completion times and the times measured in the free collaboration session. We also observed that the average actual performance times when roles were assigned was *lower* than the average times during the free collaboration session. This indicates that participants spent significantly less time to complete the task when roles were assigned, which demonstrates that **assigning roles to users improves the group interaction and performance**. In conclusion, we confirm the effectiveness of role-based collaboration when employing the first user modeling approach (i.e. identifying the combination which gives the minimum total time in completing the collaborative task).

For the other three approaches, we found that task completion times do not differ significantly across the actual and free times. However, the average actual task completion times was found to be *lower* than the one of the free collaboration. These findings show that the role-based collaboration is not quite effective when employing these user modeling approaches (i.e. *Exclusion of worst individual performance*, *Minimum performance gap*, *Maximum preference*) as it shows **no significant improvement in the group performance**.

5.2 Case Study 2: Remote collaboration

For the second case study, the same four user modeling approaches are applied. The only difference is since we limit every participant to only have one certain device available, we will have two best predicted combination of action and device for every pair (e.g. one best combination determined when the first participant has the SpaceMouse, and another best combination determined when the first participant has the Phantom). Table 2 summarizes the results of the hypotheses tested in this case.

Effectiveness of collaborative user models. Every approach showed its effectiveness in constructing collaborative user models since we found no significant difference across the modeled task completion times and the actual times measured as a result of role-based collaboration. This indicates that **the collaborative user model constructed has proven to be a good approximation to the actual performance.** Therefore, we can draw the same conclusion as in the first case study, that all four proposed user modeling approaches are valid to construct collaborative user models.

Effectiveness of role-based collaboration. In two approaches, *Minimum total time* and *Maximum preference*, role-based collaboration showed its effectiveness in enhancing the group interaction and performance. This is shown by the significant decrease of completion times, which confirms that **the assignment of roles to users can greatly improve the group interaction and performance**. Hence, we can conclude that both user modeling approaches (i.e. determining the combination that gives the minimum total time and maximizing users' preference) are effective.

The other two approaches, *Exclusion of worst individual performance* and *Minimum performance gap*, showed that the average actual task completion times was *lower* than the one of the free collaboration but the difference was not significant. In conclusion, role-based collaboration is not quite effective in these approaches since **no significant improvement in the group performance** is observed.

5.3 Comparison of proposed user modeling approaches

Due to the different aims of collaboration, it is obvious that no single best approach will work for every pair of collaborators. However, we are interested to outline which one of the proposed approaches can be mostly appropriate and effective in both situations of collaboration: co-located and remote. We would also like to confirm whether or not the four user modeling approaches can be applied in both situations.

Two-way repeated measures ANOVA showed a significant main effect of the *user modeling approach* on task completion time ($F_{3,57} = 6.17$, $p<0.005$). This indicates a significant difference among the four approaches across both co-located and remote collaboration. Post hoc tests revealed that the average task completion times of the *Minimum total time* approach was significantly lower than of the other approaches ($p<0.05$). We also found that there was no significant interaction effect between the *user modeling approach* and the *type of collaboration*. This finding suggests that all four user modeling approaches can be used in the same manner, no matter in which situation users are collaborating, either co-located or remotely-located.

Table 1. Case study 1: Co-located collaboration.

Approach	Statistics	Hypothesis confirmed?
H1: The modeled task completion time will not differ from the actual time		
Minimum total time	t(9)=0.212, p=0.837	Yes
Exclusion of worst performance	t(9)=1.976, p=0.080	Yes
Minimum performance gap	t(9)=0.159, p=0.877	Yes
Maximum preference	t(9)=0.981, p=0.352	Yes
H2: The actual task completion time will be lower than the time during the free collaboration		
Minimum total time	t(9)=2.302, p=0.047 M_{actual} (M=219.3 s) < M_{free} (M=283.5 s)	Yes
Exclusion of worst performance	t(9)=0.465, p=0.653 M_{actual} (M=237.5 s) < M_{free} (M=250.9 s)	No
Minimum performance gap	t(9)=1.291, p=0.229 M_{actual} (M=225.8 s) < M_{free} (M=263.7 s)	No
Maximum preference	t(9)=1.517, p=0.164 M_{actual} (M=219.3 s) < M_{free} (M=267.9 s)	No

Table 2. Case study 2: Remote collaboration.

Approach	Statistics	Hypothesis confirmed?
H1: The modeled task completion time will not differ from the actual time		
Minimum total time	t(9)=1.424, p=0.171	Yes
Exclusion of worst performance	t(9)=1.747, p=0.097	Yes
Minimum performance gap	t(9)=0.996, p=0.332	Yes
Maximum preference	t(9)=1.417, p=0.173	Yes
H2: The actual task completion time will be lower than the time during the free collaboration		
Minimum total time	t(9)=2.776, p=0.012 M_{actual} (M=215.3 s) < M_{free} (M=270.0 s)	Yes
Exclusion of worst performance	t(9)=1.635, p=0.119 M_{actual} (M=237.0 s) < M_{free} (M=270.0 s)	No
Minimum performance gap	t(9)=1.866, p=0.078 M_{actual} (M=233.9 s) < M_{free} (M=270.0 s)	No
Maximum preference	t(9)=2.579, p=0.018 M_{actual} (M=219.4 s) < M_{free} (M=270.0 s)	Yes

We can conclude that, all in all, the *Minimum total time* is the most effective and appropriate approach to be employed in both situations. However as previously mentioned, no single approach will work best since every group may have different goals of collaboration. Therefore, other models can be also widely applied based on the goal of collaboration. They may not guarantee the best performance time but will take into account other important aspects of collaboration (e.g. preference, equal performance, etc.). Although the user modeling approaches have only been validated in a 3D puzzle game, we believe that these approaches can be applied to a wider range of collaborative 3D games.

6 Conclusion

We have presented an investigation of adaptation of users' roles based on the availability of devices to enhance group interaction in a collaborative 3D game. Four different approaches to build collaborative user models were proposed and validated through an experiment. These models were based on different purposes of collaboration. We presented a detailed analysis of every approach for two situations: co-located collaboration and remote collaboration. The *Minimum total time*, a user modeling approach by determining the combination that gives the minimum total time, is found to be the most effective approach in both situations. We have demonstrated that incorporating adaptation of assigning roles to users based on a collaborative user model built using this approach, improves collaboration between two users.

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