Enhancing Group Interaction in Collaborative Virtual Environments through Context-Based Adaptation

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ABSTRACT
This paper addresses our effort of investigating context-based adaptation as a prospective solution to enhance group interaction in collaborative virtual environments. Through our work, we aim to provide adaptation of assigning users' roles based on the context of users when collaboratively interacting in a virtual world. We describe an experiment to assess whether the adaptation results in an improved group collaboration in virtual environments or not. From the experiment, we learned that the context-based adaptation of assigning roles to users improves the group performance in collaborative virtual environments.

Author Keywords
Adaptation, context, collaborative virtual environments

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Miscellaneous; H.5.3 Group and Organization Interfaces: Computer-supported cooperative work; I.3.7 Three-Dimensional Graphics and Realism: Virtual reality

INTRODUCTION
Collaboration in virtual environments becomes more popular during the last decades due to the rise of Massive Multiplayer Online Role Playing Games (MMORPG) such as World of Warcraft[1] and virtual communities such as Second Life[2]. Collaboratively interacting in virtual environments has its own challenges compared to other types of collaborative work. A collaborative virtual environment involves a group of users performing highly interactive tasks with the use of three-dimensional (3D) user interfaces, while trying to achieve effective and efficient collaboration. Another complexity of working in collaborative virtual environments is the variety of 3D interaction tasks and techniques; the performance and preferences of every single user may differ which in the end may influence the group collaboration. Providing adaptation according to the context of users is considered beneficial to improve their interaction in virtual environments, not only individually but also as a group collaboratively. To enhance group interaction in collaborative virtual environments, we envisage that providing adaptive interaction according to the individual context of users would be a prospective solution.

Through our work, we would like to investigate if context-based adaptation leads to enhanced group interaction in collaborative virtual environments. This paper describes an experiment which attempts to investigate how adaptation based on the context of users' role and device used can benefit collaboration within a virtual world.

ADAPTATION IN VIRTUAL ENVIRONMENTS
Interacting in virtual environments is mostly associated with complex interaction where users have to perform complicated tasks with highly interactive 3D user interfaces. Different user characteristics influence user interaction in virtual environments and lead to performance deviation among users. Adaptive user interfaces can be considered as one way to accommodate these individual differences and level up users' performance [1]. Integrating adaptation into virtual environments, by providing adaptive user interfaces according to users and other contexts, is considered as a key to comply with user's differences and enhance user interaction.

We acknowledge the importance of providing adaptation in virtual environments to enhance user interaction. The adaptation should take place according to the current context, for instance the environment condition of the virtual world and the preferences and abilities of the users. Not much research has been done on adaptation in virtual environments compared to WIMP applications, nonetheless, few works have yielded adaptivity of interaction in virtual environments by means of learning user behavior and preferred method of interaction [4, 14].

Using a context-aware design process, we have incorporated adaptation in virtual environments [8]. We experimented with providing adaptation to users based on their individual context, such as switching between interaction techniques (based on personal preference) and adapting the interaction technique itself (based on motor ability). When performing one task in virtual environments, users may prefer one technique to another depending on the environment condition or view

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

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of the virtual world. Thus, given users' preference as context, we can enable users to switch between interaction techniques as a form of adaptation. Different motor abilities may affect users' performance in virtual environments, for example one user who has hand tremor may perform an interaction technique less accurately than healthy users. Therefore, the interaction technique can be adapted by adjusting its parameters (e.g. viscosity) accordingly to comply with the user's specific characteristics (e.g. hand tremor).

Adaptation through context-awareness

Over the past few years, a considerable amount of research has been done in context-aware computing. Dey [5] described the general definition of context, which is likely the most popularly used in every HCI field: *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between the user and the application, including the user and the applications themselves."*

The use of context for making decisions about adaptation in virtual environments has grown significant interests in the research community. Classification of context and attempts to support context-based adaptation in virtual environments, either for single-users or for collaborative settings, have been less investigated. Our previous research [8, 13] has investigated an approach for detecting and switching context for contextual interaction in virtual environments and integrating adaptation in virtual environments using a context-aware design process. In those works context was defined by the available input and output devices, and also external parameters such as the experience level of the user, whether or not there are collaborative partners in the environment, or even the pose of the user (sitting or standing). Other research [6, 9] has been investigating the support of context-based adaptation within a virtual environment.

COLLABORATION IN VIRTUAL ENVIRONMENTS

Collaboration in virtual environments has been studied quite extensively for the last few decades. Many collaborative virtual environments (CVEs) have come into existence. However, most of them have limited interaction possibilities and have not widely supported highly interactive activities yet. Nevertheless, there are few studies [10, 12] which have investigated people collaborating to perform interactive tasks. For example, in [12] all participants had to complete different subtasks in order to achieve the task goal. The variation of performance based on the available output devices was investigated in this work. In our opinion it is interesting to see if the adaptation of the tasks based on the devices would increase the performance.

Another example of highly interactive collaboration can be found in [10], which investigated collaboration of two participants on Rubik's cube task. They compared performance between real and immersed setup, which showed to be almost the same. Their analysis showed high rates of these two setups comparing to the desktop one. It also showed that the participant using desktop contributed less to the task and did not enjoy the collaboration. Based on this, it may be interesting to improve collaboration by adjusting the desktop user performance by assigning him certain activities that can be done easily by him. This can be seen as one example where adaptation based on the devices and performance can benefit the collaboration of several people.

Our previous research [3] investigated different factors that influence collaboration in a virtual environment, namely communication and variety of input devices. The experiments showed that there is a correlation between the devices used with the roles taken. It was natural that participants divided their roles based on their convenience with the device. But this division was done explicitly only when communication was allowed. For no communication cases, it was not possible to divide the roles explicitly. We believe that this issue can be solved by automatic adaptation of users' roles in collaborative virtual environments.

CONTEXT-ADAPTIVE COLLABORATION IN VIRTUAL ENVIRONMENTS

Numerous works in the field of CSCW and mobile applications have tried to provide adaption based on context to improve group collaboration [7, 15]. However, context-adaptive interaction has received less attention in virtual environments. Working in virtual environments is always more challenging than the real life situations. Interaction becomes more complicated and not always straightforward for users. That is why it is important to implement adaptation within these systems to make interaction easier and more enjoyable. As previously mentioned, a lot of research has been done that focused on the improvement of the user performance in a virtual environment by adapting interfaces, interaction techniques, etc. But no work is known so far which tries to adapt the interaction in a collaborative virtual environment.

One phenomenon of recent CVEs is their rapidly increased popularity and ability to unite thousands people all over the world (e.g. MMORPG and virtual communities). The main aim for developers now is to support interaction of these users, which can be achieved for example by providing different services based on their context [2]. Another approach to provide enhance collaboration is a context-aware communication support for remote gamers [11], which can improve a gaming experience by integrating voice interaction between users based on game context. At the moment, no work is present which describes how the virtual worlds and communities can benefit from adaptation based on users' context. Adaptation may play an important role in elevating user performance in such dynamically changing virtual world. Therefore, we consider that through context-based adaptation users can achieve more enjoyable interaction within the virtual world.

The aim of collaborative virtual environments should be to achieve group goals, not individual goals of each user involved in the collaboration. Group interaction and performance may be enhanced by integrating adaptation into collaborative virtual environments. To provide adaptation in a collaborative setting, we consider an approach of employing a group context which is based on the individual context of users involved in the group collaboration. Therefore, we would like to investigate the possibility of combining individual contexts into group context. We consider that single-user based adaptation for a collaborative environment, where adaptation is performed separately for each user involved in the collaboration, does not lead to an adaptive collaborative environment. Additionally, it is essential to examine the integration of exogenous context factors (e.g. location, device used) with endogenous ones (e.g. users' roles, experiences) to provide better and more accurate adaptation in collaborative environments.

In this paper we investigate a combination of endogenous and exogenous factors to assess if context-based adaptation leads to enhanced group interaction (i.e. higher productivity) in collaborative virtual environments. For this purpose, we carry out an experiment to investigate how adaptation based on the context of users' role and device used can benefit collaboration within a virtual world. While performing a collaborative 3D puzzle solving task, users' roles can be divided based on their individual performance in executing 3D object manipulation task. For example, one user may be better at rotating objects while the other is better at translating objects.

PROPOSED USER MODELING APPROACH

Based on the aforementioned findings, we propose adaptation of users' roles such that it will result in a better group interaction. To determine the adaptation, we propose an approach to construct a collaborative user model based on users' individual performance. The purpose of this user modeling approach is to come up with the best prediction of role combination for providing adaptation of assigning users' roles (i.e. deciding which roles are appropriate for the users) to enhance the group interaction. In this work, we suggest a '*minimum time*' approach as a way to build the collaborative user model. In this approach, we estimate the task completion time for every possible role combination and then select the combination which gives the minimum estimated total time as the best role combination. To estimate the task completion time, firstly, we calculate for every user the time to perform each role separately. Then for all combinations of roles, we calculate the total time to perform both roles collaboratively. Furthermore, to validate this approach, we will compare the findings based on our proposed approach with a so-called '*ideal time*', which we consider as the shortest task completion time of all possible combinations.

EXPERIMENT

Our work attempts to enhance group interaction by providing context-based adaptation in collaborative virtual environments. The adaptation is determined based on the context of users' role and device used when collaboratively interacting in a virtual world. To achieve this, we conduct an experiment to investigate the performance of users in pairs while executing an interactive 3D puzzle solving task, which is considered to be highly collaborative. The experiment is designed based on [3] which showed that users explicitly divided their roles during collaboration based on their convenience with the device being used. With our experiment, we aim an improved group interaction by constructing a collaborative user model that suggests the adaptation of assigning users' roles based on their individual performance when executing a certain task (e.g. rotation, translation) using a certain device (e.g. SpaceMouse, Phantom). Through this experiment, we would also like to validate our proposed approach in constructing the collaborative user model.

Hypotheses

For the best combinations predicted by the collaborative user model, five hypotheses were formulated in this experiment: (1) The estimated task completion time based on the model will not differ from the actual task completion time, (2) The estimated task completion time based on the model will be lower than the free-collaboration task completion time, (3) The actual task completion time will be lower than the free-collaboration task completion time, (4) The estimated task completion time based on the model will not differ from the ideal time, and (5) The actual task completion time will not differ from the ideal time.

Methods

Participants

Ten randomly coupled pairs of unpaid volunteers (4 females and 16 males, 23 to 34 years old) participated in the experiment. Most of the participants had little experience with a virtual environment and also with the devices involved. All participants were right-handed and used their dominant hand to operate the device during the experiment.

Apparatus

For the experiment, two input devices, a SpaceMouse and a Phantom, were available for each user. Two desktop computers with 19" monitors as the display were used in the experiment. During the experiment, participants were located in the same room and close to each other, however, they were seated as such that it was impossible to see each other's screen. Figure 1 illustrates the experiment apparatus and settings.

Figure 1. The experiment setup.

Design and Procedure

The experiment consists of three parts: an individual session, a free collaboration session, and a role-dependent collaboration session. The first session aims to gather the data of each user's performance individually, with regards to the combination of roles and devices. The second and third session aim to gather the data of users' performance in pairs; in the second session there is no division of roles while in the third session the division of roles are specifically defined. Two roles were defined in the experiment: rotation and translation. Table 1 presents the complete overview of the experiment sessions.

The collaboration sessions of the experiment were designed as within-subjects[3] designs. For the free-collaboration session, the independent variable was the device used (SpaceMouse, Phantom). For the role-dependent collaboration session, the independent variable was the combination of role and device (Rotation SpaceMouse, Translation SpaceMouse, Rotation Phantom, Translation Phantom). Task completion time was measured as the dependent variable.

Individual Session	
Participant 1	Participant 2
Rotation SpaceMouse	Rotation SpaceMouse
Translation SpaceMouse	Translation SpaceMouse
Rotation Phantom	Rotation Phantom
Translation Phantom	Translation Phantom
Free Collaboration Session	
Participant 1	Participant 2
Free SpaceMouse	Free Phantom
Free Phantom	Free SpaceMouse
Role-Dependent Collaboration Session	
Participant 1	Participant 2
Translation Phantom	Rotation SpaceMouse
Rotation Phantom	Translation SpaceMouse
Translation SpaceMouse	Rotation Phantom
Rotation SpaceMouse	Translation Phantom

Table 1. The experiment sessions.

We asked every pair to complete ten puzzle solving tasks. Each puzzle consists of 12 cubes representing a picture, where one cube was already placed to serve as a visual guide. The cubes, with part of the picture on one side, were dispersed in the virtual environment (see figure 2). During the experiment, participants need to indicate the starting and ending time of the session by selecting the menu items ("Rotation/Translation" to start the first and third session, "Start" to begin the second session, and "Finish" to end all sessions as soon as the task was completed). Participants were allowed to talk during the experiment. At the end of each session, we asked the participants to fill out a questionnaire about their experience and preference based on [12]. Each pair completed the experiment in 60 minutes on average.

Results

In this paper, we focus on improving group interaction in a collaborative virtual environment by providing adaptation of assigning users' roles based on a collaborative user model. The collaborative user model was built based on the users' individual performance and gives information about the best combination of roles and devices for a particular group. To investigate the efficacy of the model, we compared the estimated task completion time based on this model with the actual task completion time of that particular combination. Furthermore, we found it interesting to compare the model and actual time with the task completion time measured during the free collaboration session, in order to demonstrate that implementing adaptation for role-dependent collaboration would significantly decrease task completion time, thus enhance group interaction.

[3] Subjects are defined as pairs

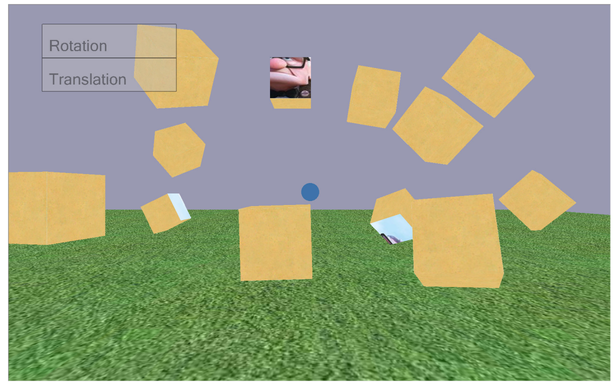

Figure 2. The puzzle solving task in the experiment.

As previously mentioned, we employ our proposed '*minimum time*' approach to determine the best role combination as the collaborative user model. In this approach, we estimate the task completion time by first estimating the time to perform each role per cube for every user (e.g. to translate one cube with SpaceMouse). Then for all combinations of roles and devices, we calculate the total time to rotate and translate one cube, afterwards we estimate the total time to complete the whole task collaboratively. As a result, we determine the minimum estimated total time which then define the best role combination as well.

For the first hypothesis, a paired-samples t-test showed no significant difference between the model time and the actual time [$t(9) = 0.212$, $p = 0.837$]. This indicates that task completion times do not differ significantly across the model and actual times. We can conclude that our model can be considered as a good approximation to the actual condition.

For the second and third hypothesis, paired-samples t-tests showed statistically significant differences between the model time and the free time [$t(9) = 3.508$, $p = 0.007$], and also between the actual time and the free time [$t(9) = 2.302$, $p = 0.047$]. These findings indicate task completion times differ significantly across the role-dependent collaboration (model and actual) and the free-collaboration times. The average task completion times for cases where roles were introduced (model [$M = 217.8$ s], actual [$M = 213.9$ s]) were lower than for cases where roles were not present (free [$M = 283.5$ s]). Based on these results, we can conclude that assigning roles to users improves the group performance.

For the fourth hypothesis, a paired-samples t-test showed a statistically significant difference between the ideal time and the model time [t (9) = 2.547, p = 0.031], which indicates task completion times differ significantly across the ideal and model times. The average task completion time for ideal [M= 180.3 s] was lower than for model [M= 217.8 s]. For the last hypothesis, another paired-samples t-test showed no significant difference between the ideal time and the actual time [t (9) = 2.191, p = 0.056], which indicates task completion times do not differ significantly across the ideal and actual times. Based on these findings, we can conclude that we have successfully selected the right combination of roles, however, our time estimation based on the model is not precise enough as it is not close to the actual shortest (ideal) time. Consequently, we can claim that our model is effective to determine the right combination of roles and devices but the time estimation is not yet accurate.

CONCLUSION AND FUTURE WORK

We presented an investigation of context-based adaptation as an approach to enhance group interaction in collaborative virtual environments. We have described an experiment to examine how adaptation according to the context of users (i.e. users' role and device used) leads to improved group collaboration (i.e. faster task completion time) in virtual environments. We found out that assigning roles to users improves the group performance. The effective assignment of roles was ensured by our model developed in this work.

Building other models for determining the roles assignment may be interesting, for example models that take into account users' preferences or which attempt to balance users' contribution to the task by minimizing the performance difference between them. Furthermore, it would be interesting to discuss models for determining the best role assignment that is suitable for a setup where only a certain and not all devices are available.

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