AMMP-EXTN: A User Privacy and Collaboration Control Framework for a Multi-User Collaboratory Virtual Reality System

AMMP-EXTN: A USER PRIVACY AND COLLABORATION CONTROL FRAMEWORK FOR A MULTI-USER COLLABORATORY VIRTUAL REALITY SYSTEM

by

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Under the Direction of Ying Zhu

ABSTRACT

In this thesis, we propose a new design of privacy and session control for improving a collaborative molecular modeling CVR system AMMP-VIS [1]. The design mainly addresses the issue of competing user interests and privacy protection coordination. Based on our investigation of AMMP-VIS, we propose a four-level access control structure for collaborative sessions and dynamic action priority specification for manipulations on shared molecular models. Our design allows a single user to participate in multiple simultaneous sessions. Moreover, a messaging system with text chatting and system broadcasting functionality is included. A 2D user interface [2] for easy command invocation is developed in Python. Two other key aspects of system implementation, the collaboration Central deployment and the 2D GUI for control are also discussed. Finally, we describe our system evaluation plan which is based on an improved cognitive walkthrough and heuristic evaluation as well as statistical usage data.

INDEX WORDS: Collaborative Virtual Environment, Access control, Privacy protection, Molecular modeling, GUI, CVE survey, System evaluation

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DEDICATION:

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LIST OF ABBREVIATIONS

GUI	Graphical User Interface
UI	User Interface
CVE	Collaborative Virtual Environment
WYSIWYG	What You See Is What You Get
CSCW	Computer Supported Cooperative Work
AG	Access Grid

CHAPTER 1: INTRODUCTION

Collaborative Virtual Environment (CVE) [3] is a virtual world that is designed to support collaborative work among distributed users. CVE provides an extensible, populated 3D space in which multiple users can interact with each other through text, audio/video, gesture and expression, and also interact cooperatively with data representations as virtual objects. It brings together people from different physical locations to work in a shared environment.

Two important issues of CVE design are user access control and subjective view provision. Most of the existing CVEs provide a single-viewed shared world to every user, following the principle of WYSIWIS (What You See Is What I See) [4] interface. This single user prospect facilitates users' mutual awareness and eliminates the complexity of view control and environment representation in supporting individual views. However, user experience with CVE applications based on WYSIWIS principle suggests its limitations [5-7]. While it is useful to have a common VE display for collaboration, sharing everything in a VE denies a user's privacy as a user may hope to have exclusive control over an object or keep himself/herself invisible to others. In a collaboration environment, there may be competing demands for accessing shared resources and for setting individual privileges over shared objects.

1.1 Motivation

The motivation of improving the single view CVE comes from the user feedback of a CVE for molecular modeling - AMMP-VIS [1]. In this single view CVE, biologists are limited to working on one molecule model. It is impossible to open multiple model files and do cross-model manipulation and comparison. Some 2D molecular modeling CVE applications [8, 9] allow multiple models to be loaded into the single view and placed pairwisely. However, in our AMMP-VIS real-time immersive visualization, loading each molecule model requires the transmission of the model or visualization from server to each remote collaborator, periodical update of the model synchronization, and energy field calculation. This is not necessary unless the model keeps on changing under frequent manipulation of collaborators. In most cases, biologists need to frequently interact with only one molecule model. We can visualize the non-manipulated molecule models in a view separate from the collaborative view. This motivates us to consider developing multiple view for molecule visualization in order to avoid unnecessary and expensive data transmission.

There is another reason for displaying multiple molecule models in more than one view. Deciding where to place several molecule models in the 3D immersive view is not easy. If we put them nearby and close to the initial view point of the collaborators, they will interfere with each other when they are dragged and moved in the 3D space. If they are scattered across the VE, then biologists will have difficulty finding them and arrange them in appropriate positions to help comparison. The process of user traveling in the VE and searching for objects is inconvenient.

In addition to multiple model visualization, there are a few other aspects of system design that require improvement. Biologists who build and manipulate molecule models cooperatively in AMMP-VIS generally feel difficult to focus on a mutually interested part due to the lack of communication method for referencing (e.g. suggesting where to look at). Teleconference tools may be included to facilitate user intention awareness. Embedded 3D virtual menu [10] is not only hard to manipulate but also limited to its menu choices. Users expect an easy-to-use interface to support command invocation.

Another critical issue for AMMP-VIS collaboration is that the molecule modeling is a knowledge discovery process. Any moment there may be patented products which require privacy protection on the user's data [11]. We need to restrict certain users or user groups in order to protect intellectual properties. Privacy control should be established to restrict user access and user action priority need to be properly specified so that only trusted users can have access to interested models or parts of the models.

1.2 Contributions

In this thesis, we propose some new design strategies to improve AMMP-VIS collaboration control and user management functionality. To provide multiple model visualization in a single shared view, we propose the design of multiple simultaneous visualization sessions for each collaborator. Users are allowed to participate in more than one session and switch among different collaboration groups. This has provided more flexibility in user group formation. For the problem of user privacy protection, we propose a four-level access control model [11] to manage the visibility and manipulability of shared modeling session and resources. Within each collaborative modeling session, we define action priority rules for participants to ensure that the session creator always has the highest access privilege and action priority. A python 2D GUI for command invocation is implemented. It emulates existing 2D molecule modeling software interface in that users can use mouse clicking to easily select commands from the GUI instead of using the virtual menu.They can also toggle between the 3D immersive VE and the 2D GUI using a "world shift" button.

Other improvements to AMMP-VIS include the mechanism to enhance user presence awareness and awareness of collaboration status by system message broadcasting for user solicitation, entering and leaving, function for adding and deleting collaborators; a text chatting tool; a view sharing function similar to the “teleport” [12, 13] technique used in some VR games, such that one user can acquire the perspective of another user; a user status and behavior log file that provides evidence for system evaluation.

The effectiveness and usability of any system design can not be proved unless the system is evaluated with qualitative and quantitative measurements. We propose some test and evaluation methods for the AMMP-EXTN design. We modify existing HCI evaluation methods and propose a method to collect dynamic usage data for measuring system usability. In particular, we discuss how to collect user data automatically [14], by recording traces of the user activity the usage log will be processed to extract user events that may indicate usage problems.

1.3 Benefits

The proposed enhancement to the single-view CVE of AMMP-VIS is expected to increase users’ interest in taking part in collaborations while preserve their privacy. Instead of providing a single shared view [1], our design allows users to work in multiple modeling sessions simultaneously with different access privileges. Users can have a private “local” modeling process on the client machine while participating in multiple collaborative sessions at the same time. The session creator can specify the access privilege both for her session and for any participants based on the access control rule we propose. It is also possible to change input priority among the group of collaborators at any time in their collaboration.

1.4 Thesis Outline

The following chapters are organized as follows. Chapter 2 brief reviews the Collaborative Virtual Reality (CVR) concept and technology. It explains the user-related high level design issues and discusses the major design issues we focus on. Chapter 3 proposes a taxonomy of CVR systems based on the major types of user activity each system supports. We study their design concepts and concentrate on how they address the user-related design issues listed in Chapter 2. The rest of the thesis is based on the research for improving the AMMP-VIS CVR molecular modeling system. Chapter 4 proposes a hierarchical access control model and presents the design of multiple simultaneous collaborative sessions. We explain the enhancement to user presence awareness by providing communication capability that support system and user messages. Chapter 5 describes the system implementation. The design constraint of the multiple sessions, the idea of distributed collaborative Central for collaboration management and the implementation of the 2D control interface are discussed, followed by the description of our proposed evaluation plan in chapter 6. Finally, in Chapter 7 we summarize our contribution and discuss future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Collaborative Virtual Environment Concept

The concept of CVE belongs to the discipline of computer supported cooperative work (CSCW) [15]. Earlier CSCW products include desktop and video conferencing, bulletin board that provide shared media for multiple users. These traditional groupware often gives 2D data representation with limited interactive space, and support limited user-user and user-system interaction. Compared to the CVE, users are confined to the single 2D interface [16], restricted by the system limitation to communicate freely, unaware of others presence, need and action.

VE technology has offered the sense of immersion, interactiveness and emulated realism to computer aided social work. By adding the functionality that supports closely-coupled [17] collaborative interaction, CVE enhances the capability of CSCW to facilitate mutual, cooperative problem solving and research discovery. It no longer restricts user to the simple activity of information entering and viewing, and single channel communication. The virtual space is designed to be explorable and modifiable [6], some with unlimited special and temporal boundary. Users are aware of each others presence by the artificial avatar embodiments or embedded sounds/video channels. Continuous body movement and facial expression can be tracked and mapped to the virtual avatar by the latest Immersive Projection Technique (IPC) [17]. In addition, participants can customize their perspective to suit their need, define action priority rule to maintain orderly collaboration, and exert control over their privacy. Every possibility of human interaction in the real world may be expected and enhanced by the CVE.

Such interaction requirements from collaborators define the characteristic of the collaborative work scenario in CVE, as Churchill et. al, proposes in their VR 98' introductory review [18], CVE design must support one of the following collaborative features: the transition between co-op and single activities, flexible user view, context and knowledge sharing, negotiation and communication, user awareness.

Research interest in CVE is sparked by a variety of scientific and application field. The importance of physical space for promoting interaction awareness, negotiation and objects sharing was studied in [19]. For tele-communication and cooperation system, the advantage of collaboration in a shared virtual space can establish unprecedented facility that is not readily supported by videoconferencing tools [20]. CVE also has the potential to provide scalability in crowded human behavior [21], such as auction and touring, where thousands of users actively engaged in all sorts of activities, making groups, conflict and negotiate. Further more, participants in a collaboration-centered work environment will benefit from the action rule and the order CVE provides. For example, a typical scenario of our AMMP-VIS [1] CVE includes a group of biologists discussing and manipulating shared molecular models in such a way that each user can have the right to monitor the resource access, control session progress and negotiate action priority.

2.2 High-level Design Issues for Collaboration in CVE

Through the course of CVE research and application development, it has been acknowledged that user behavior support and management is one of the most subtle and demanding part of the design [22]. Special consideration should be made to solve problems, such as recognizing multi-user presence, tendency and interest, when single-user VE strives to scale up and support multi-user synchronization. Compared to the human related problems, issues that affect system speed and accuracy, such as how to design the network structure, deploy resource and provide communication can be easily thought of and handled based on existing industry standards and techniques. As an example, we can utilize the data duplication technique on the collaboration server to increase data access speed for client-server system architecture. Text and Voice chatting ability is provided to the single VE by integrating a third-party communication tool.

However, usability concern on the easiness and readiness of the system to its user is often overlooked or underestimated, as pointed out in [23] that much CVE research is devoted to the development of support tools and the minimization of network traffic. A CVE with quick system access but unfriendly user interface and poor collaboration utilities can hardly attract user while if participants can have flexible environment control and easy mutual interaction, they will generally tolerate a little slowness of the access. We describe the performance issues subject to human cognition and behavior as high-level design issues. Benford et. al [24] has proclaimed that human factor will present new challenges for understanding social interaction in CVE. Hence, with small attention but not complete exclusion of the hardware and system configuration issue, we focus on the high level user problems. In an attempt to illustrate the user demand of our AMMP system and exemplify various solution methods, we give a list of major high-level design issues and corresponding design approaches.

2.2.1 Shared and Subjective View Support

Although user view design in CVE is based on the principle of WYSIWIS proposed by the earlier CSCW field [15], it is equally important for CVE to support user control on their own unique perspective. Such subjective view can reflect different user attention and the roles in the shared world. The impetus of collaborators to have customizable view is illustrated by an example in Churchill et. al's CVE review [18]. In a collaborative house design, different types of technicians want to see different features related to their specialty field. Electricians like to see the wiring plan while carpenter need the plumbing layout most of the time. In a CVE that emphasize selection and manipulation interaction, different user usually hopes to tailor the object representation to suit their focus or interest. We see the effort of supporting multiple views in the early CVE work, DIVE [25] for example, which defines a user access model that controls different user interface representation.

In our AMMP-VIS system, when biologists are collaboratively study a molecule model, shared view is required for the most time so that collaborators can see their simultaneous actions and result update. AMMP-EXTN attempts to satisfy user desire for subjective view by allowing individuals to customize view parameters for the same molecular data visualization on different client computers and by forming collaboration groups with authorized access privilege to certain molecule data or model. Other collaborative molecular modeling CVRs [8-10] only allow a user to participate in one collaboration session and work on one data model. We plan to provide user access to multiple simultaneous sessions that can be either private or collaborative sessions. Therefore, it is possible to watch a model under manipulation in a shared collaborative view while observe the model from a different perspective in a local single-user session.

2.2.2 User Privacy and Cooperation Initialty Management

Protecting user privacy and promoting cooperation desire are two conflicting user demands in CVE system. CSCW promote cooperation by advocating the same shared view (WYSIWIS) that simplifies the environment representation. However, user privacy is reduced to almost none without any means to hide user presence, information and their action. In a collaborative visualization system, the viewing of certain information may need to be restricted to a user group [26]. The communication among users may require secrete channel and the visibility of user presence may be specified.

A more challenging demand of privacy control may require the virtual environment to be reconstructable according to user need. For example, in a virtual office VR [27], user may want to set up separation and blockade to define their personal space. When a biologist in the multi-user AMMP collaborative session makes discovery and hope to have inclusive control over the related objects, he/she should be able to "lock" the object at least temporarily to prevent other's access. While this may affects collaboration and tends to discourage cooperation initialty, a suitable handling that takes proper tradeoff between the two issues can improve user flexibility and reduce the occurrence of privacy violation.

Users who collaborate in the molecule modeling VE also require privacy protection, as indicated by users of AMMP-VIS. Although most of the time collaborators need a shared view, in certain occasions a user may want to hide his/her presence, action, usage history and part of a molecule that he/she is working on. Such concern has never been addressed in previous molecule modeling CVRs. In AMMP-EXTN, we proposed a user privacy control framework [11] to specify different access priority to the shared resources.

2.2.3 Collaboration Synchronize and Action Priority Arbitration

In the collaborative circumstance with simultaneous interaction, a mechanism must be established to maintain orderly interaction on shared object. Dewan [28] has proposed a fine-grain access control framework that ensures sequential access to shared resources. The integrity of object and consistency of action result are what the access control module needs to check. Alternatively, user action priority may follow some social convention. In MASSIVE-1 [9], only one participant is allowed to speak at any moment. User may raise their hand to indicate their talking desire and let the system decide whose speaking ability will be enabled. In many CVE computer games, different character roles have pre-defined different levels of action priority so that it becomes easy to break a tie of simultaneous object access without using kernel level process synchronization. Another difficulty in access control is to make this process [29] transparent to users. The multiple distributed user process should be invisible to individuals for fulfilling a natural interaction. Simultaneous dragging of the same atoms by different users is avoided by defining the interest bounding box in AMMP-VIS. If a set of atoms fall into the bounding box defined by one user, only this user is able to manipulate those atoms at that moment until he/she cancels the bounding box selection. User action priority can be specified in AMMP-EXTN to further enforce the order of object access. In case that different collaboration groups work on the same data file and make changes simultaneously, the server will keep copy of different resulting files using file synchronization techniques provided in [28].

2.2.4 Transition from Collaboration to Single Work Scenario

Collaboration work is interleaved with individual and group activity [15]. Although CVE is designed mainly for supporting multi-user group activity, it should also support the independency of single user's effort. Single user support includes not only the requirement that the system can operate with only one active user but rather to provide an environment that an individual can feel separate from and be indifference to other collaborators and group actions. In a spatial dividable CVE, for example, virtual exhibition, doors may be the interface for user to enter/exist rooms occupied by different user groups. The SPLINE [30] system divides the virtual world into different sized “locals” (like cubic). Participants do individual work in one “locals” while they can contact and collaborate with those in the neighbor “locals”.

On the other hand, a temporal divided CVE like our AMMP-VIS system will need supplemental interface between individual and group scenario, which can not be explicitly derived from the real world model. User may wish to hit a button or utter a command that can transfer them from the crowded collaboration session to a private individual session with the same data model while still monitoring the collaboration process. Single user support is even harder to achieve than user privacy. A user can hide his/her embodiment from public or construct a private space in the shared environment to gain privacy. However it is not easy to hide all the other co-presenters and the changes they make to the VE from one individual’s view. One of the solutions implmented in AMMP-EXTN is to design a private local session and define the transition from the collaborative work to single work. A user can change the working status from collaboration to single and the system will log out the user from the current collaborative session and create a local session in which the user will continue to work alone. Users are also able to change a private local session to collaborative by “publishing” the session to the server. There are problems that need to be considered, such as user representation after their transfer, and the retrieval of working context next time they transfer back.

2.2.5 Maintain the Collaboration Context

The context of collaboration can include a dozen of things. It may refer to the topic and focus of the collaboration, its progress, collaborators current and past activity, the shared environment status. Previous work in CSCW field has focused on the synchronous working scenario (e.g. virtual meeting, version control) [15]. Within the shared space, the collaboration context can be conveyed by communication and gesture. For example, pointing to the focused object by virtual finger gesture [31]. If the shared object is not visible to all collaborators, providing context for collaboration is more difficult. For asynchronous collaboration cases, collaboration sessions need to be saved with directions for later use. Either the user or the system has to record the collaboration history. An example of asynchronous collaboration with context preserving is the VIBE [26] bibliographic data exploration system, where message and tag can be left about changes on the document arrangement. A prerequisite for solving this issue is to address user awareness recognition. Only after users are aware of each others presence can they become knowledgeable of their aim and task and easily understand the collaboration context. In AMMP-EXTN, we have implemented a text chatting tool for communication support. In addition, collaborative session information is saved in a table format in the server database. Users who want to join the current collaborative sessions can browse the session information, such as the number of participants, the session length, the data file name and the main topic.

2.2.6 User Presence, Focus and Interest Awareness

User awareness issue concerns on the level to which collaborators in CVE can find and feel each other. A good support for user awareness can significantly promote collaboration because it increases the possibility to locate a collaborator and help users understand their intention and objective. In MASSIVE-1[9], laid down table indicate that its user is not present. User avatar can express their intention through it gestures and facial expression and thus attract others' attention. In the MUD [32] multi-player online games, system broadcasts message when a user enter or leave the game. For asynchronous CVE, such as the VR-VIBE [23], previous collaboration history is preserved and tag is left to keep track of collaborators presence. To support user focus and interest awareness, audio communication is a powerful tool. In addition, avatar's facial expression and hand gesture is also useful.

We tried to incorporate a communication function in AMMP-EXTN design to assist collaboration awareness. Users can use the text chatting tool to communicate with collaborators. Compared to the three representative molecular modeling CVEs [8-10], we are the first to integrate user communication tools. As an enhancement to AMMP-VIS CVE, our design objective is not limited to providing the collaborative visualization and modeling functions -- we also try to achieve better usability by providing a set of tools that can promote user collaboration. If a collaborator still has difficulty knowing the exact focus of his/her collaborators through chatting, he/she may want to switch to his/her collaborator's view. Thus, we design a "teleport" function in AMMP-EXTN, similar to those used in the virtual society games [12, 13], so that users can take the view points of their collaborators.

2.2.7 Support For Object-focused User Interaction

This is an important issue for the type of CVEs which involve frequent user-object interaction. Our AMMP system belongs to such type. With the WIMP (windows, icons, pointer and mouse) [33] 2D interface, object manipulation can be easily accomplished by defining mouse event in a screen based CSCW system. In an immersive 3D VR, it is difficult to gain object selection as the surface of virtual objects lack haptic feedback and the same difficulty exists for manipulation. The 3D immersive virtual Mah-jongg [34] game uses a picking pen for Mah-jongg selection. A Mah-jongg will be placed onto the table if the system detects the Mah-jongg is being moved by users to the adjacency of the table surface. Some other CVE [35] includes a touch-ball to indirectly control the strength and direction of user manipulation on another object. Still other systems [31, 36] use laser beam to extend user's scope of touch so that selection can be done by finger pointing.

AMMP-VIS represents user's hands by avatars and detects selection by avatar grab movement. However, it is still hard for users to decide the exact location of the molecule model relative to user avatar position due to lack of haptic interface. We incorporate a 2D GUI to assist user interaction with the molecule model in AMMP-EXTN. Users can select and manipulate atoms in the 2D projection view with mouse, have a quick overview of the corresponding model changes, and then goes to the 3D environment.

In nearly a decade, researchers have devoted to reconstruct single user VE with collaborative ability to suite multiple interactive users. In addition to the system example mentioned in the above paragraphs, the VR community has many successful stories for developing CVE application to solve domain specific problems [24]. However, because of the technique complexity in supporting the distributed coordination process, the uncertainty of human behavior and lack of design paradigm, the user related design issue discussed in this section still remains to hamper CVE's potential to be very useful. Many developers tend to overlook the requirement of collaboration context supply for users collaborate at different times. Many systems ignore the access control issues and give user inadequate control of their privacy. Solution to these high level design issues will become the key quality measure of a CVE, after agreement has been reached on the system architecture configuration and technique barrier lowered [37] for hardware resources. There are other user related design issues, such as how to support navigation and how to manage negotiation. In stead of listing all of them, we have selected to explain and analyze the seven most apparent issues for our AMMP design. In the next chapter, we overview representative CVE systems, especially for the purpose of visualization and we exam if and to which degree each system handle the user related system issues.

CHAPTER 3: A TAXONOMY OF CVE BASED ON THE TYPE OF INTERACTIONS

In this chapter, we review the relevant literatures of CVE system. Early work includes a taxonomy of NVE (network-based VE) given by Macedonia et.al [38] that summarized some design issues related to system architecture, an old review [18] of collaborative working characteristic in 3D CVE and exemplary systems, an overview [39] of tele-immersive CVE applications built upon the CAVE VR. Benford et. al [24] analyzed the challenge for developing CVE at the start of the 21st century. Three of the five predicted challenges are related to the user problem. These challenges are: user interest management, transfer from the traditional 2D interface to 3D VE, and new human factors. Gimstead et. al. [40] presented a detailed taxonomy of collaborative visualization system based on five system attributes, including access control and user synchronization. The investigated systems not only include CVE in strict sense, but also many multiple user environments that are constructive for supporting collaborative activity. Jensen [41] included a summary of visualization CVEs for education purpose. The summary is focused on the space sharing capability to support communication and learning. A distributed virtual lecture example is given in which user roles and action are specified.

In the subsequent section, we define new taxonomy of CVE systems which support simultaneous multiple user-model and user-user interaction. These systems include commercial applications, e.g. NetMeeting [42], Age of Empires [43] and NPSNET [44] as well as research projects such as GeoVISTA [45], Access Grid [20] and CAVE6D [31]. Our method is to create a matrix of user related design issues proposed in the previous section and investigate the methods that each system uses to handle those issues. We categorize the systems based on one of the three user activity types they mainly support: navigation, communication and selection plus manipulation. The goal of our taxonomy is to compare the systems' approaches and analyze their limitation. This analysis will then guide our design and evaluation of the AMMP-VIS CVE. As the environment for different types of social activity suggests different need of collaboration support -- for example, navigation systems usually focus on user awareness issues while communication system focuses on the availability of network channel -- we will keep in mind the design objective of each system while looking into how each of them deal with the user related issues.

Five design issues are considered (Table 3-1 a) in the User-VE interaction. User subjective view measures different viewing modes or view perspectives provided by the system, such as Bird view and First person view [12], and whether each user can selectively view different part of content of the VE. Navigation support describes the nature of the VE and in which dimension the system allows users to travel. Freedom of manipulation indicates the VE content that users can dynamically interact with. Model protection deals with user privacy and control over the VE object. It is mainly achieved by setting modeling visibility and defining object access rule. Access control inspects the granularity of the system control rule, whether it is per object, per session or per system.

For the type of interaction among multiple users, we mainly investigate three issues in the User-User interaction analysis (Table 3-1 b). They are the user action synchronization, privacy and user awareness. Synchronization means to coordinate simultaneous user interaction and update the VE so that users can have compatible view of the VE. Systems using loose synchronization usually update VE according to local users input immediately and delay updating the changes made by remote collaborators while tight synchronization means that any conflicting user action will be resolved immediately and every user has up-to-date view of the VE. User privacy refers to user communication and action privacy, whether the system support secrete talking channel and hiding of the user embodiment. The content of user awareness includes the awareness to collaborators' presence, focus and interest. It also includes the user consciousness to the collaboration context, such as the system time, place and collaboration history.

Table 3-1 a taxonomy of representative CVE systems
a. User-VE interaction

User-VE interaction					
CVE system	Subjective View	Navigation support	Freedom of Manipulation	Model Protecting	Access Control
Navigation Orientated System					
Age of Empires [43]	yes (local & global)	2D map	virtual characters the world look and feel	by game rule	per session
AlphaWorld [46]	yes (selective explore)	2D with LOD map	virtual characters and objects	yes (on some objects)	per some objects
CIS [47]	yes (allow see through of real world)	on Internet and the real world background	web pages	yes (page visibility)	per object
Diamond Park [48]	yes (three perspectives)	3D, follow defined path	bicycle	no	no
GeoVISTA [45]	no	2D map	VE part view only, real world part modifiable	no	no
GCW [49]	yes (two perspective)	3D VE (space and temporal)	the world look and feel	no	per session
VR-VIBE [26]	yes(based on standing point)	3D VE	the object and world structure	no	per system
Communication and Negotiation Orientated System					
Access Grid [20]	yes (visibility of collaborator window)	no	position of the participants windows	yes (on AG node)	per node
Greenspace [50]	no	3D VE	virtual objects	no	per session
Face Mouse [51]	no	2D space	the face mouse	no	no
MASSIVE-1 [12]	yes (10 viewing modes)	3D VE	user avatar	no	per session
MASSIVE-3 [52]	yes	3D VE	user avatar and some objects	no	per session
NetMeeting [42]	partly	2D whiteboard	user avatar look and feel	yes (shared file)	per session
VIRTUE	yes	3D VE	table shape and	no	per session

[53, 54]		projection	position		
Object Manipulation Oriented System					
CAVE6D [31]	yes (visualization)	3D VE	the model of study	no	per session
COVISE [55]	yes	3D VE	airplane model	yes	N/A
DEVA3 [56]	yes (object look)	3D VE	objects, the world look	no	per session
MUVEES [13]	yes	3D VE	objects	no	the system
NPSNET [44]	yes	3D VE	the client computer in the simulation	no	per session
SCAPE [57]	yes	3D VE and augmented obj.	the world look and feel	yes (object ownership)	per object
StudierStube [58]	yes	3D VE	the objects	yes (object visibility)	per object
DocShow [36]	yes	3D VE	the visualization	no	per session
AMMP-VIS [1, 11]	yes	3D VE	the molecular model	yes (access rule)	different level

Table 3-1 a taxonomy of representative CVE systems
b. User-User interaction

User-User interaction								
CVE system	Synchron -ization	Privacy	Awareness					
			Time	Place	History	presence	focus	interest
Navigation Orientated System								
Age of Empires [43]	loose	no	yes	yes	yes	yes (but protected)	no	no
AlphaWorld [46]	loose	communication	yes	yes	partly	yes	no	no
CIS [47]	no	no	yes	yes	no	yes	yes	yes
Diamond Park [48]	loose	no	no	yes	yes	yes	no	yes
GeoVISTA [45]	tight	no	yes	no need	no	no need	yes	no
GCW [49]	don't know	no	yes	yes	yes	yes	no	yes
VR-VIBE [26]	loose (in multicast group)	embodiment	no	yes	yes	yes (but protected)	no	yes
Communication and Negotiation Orientated System								
Access Grid [20]	no	no	no need	no need	no	yes	no	yes
Greenspace [50]	loose	no	no	no need	no	yes	yes	no
Face Mouse [51]	loose	N/A	yes	yes	no	yes	yes	yes
MASSIVE-1	tight	no	yes	yes	no	yes	yes	no

[12]								
MASSIVE-3 [52]	loose	no	yes	yes	yes	yes	yes	no
NetMeeting [42]	loose	communication and embodiment	yes	yes	yes	yes	no	yes
VIRTUE [53, 54]	NA	no	no	no need	N/A	yes	yes	yes
Object Manipulation Oriented System								
CAVE6D [31]	loose	no	yes	yes	yes	yes	yes	no
COVISE [55]	loose	no	no	yes	no	yes	no	yes
DEVA3 [56]	asynchronous	no	no	yes	no	yes	no	no
MUVEES [13]	loose	communicat-ion	yes	yes	yes	yes	no	yes
NPSNET [44]	loose	no	yes	yes	no	yes	yes	no
SCAPE [57]	N/A	no	no	yes	no	yes	no	N/A
StudierStube [58]	loose	no	no	no need	no	yes	yes	yes
DocShow [36]	loose	no	yes	no	yes	yes	yes	yes
AMMP-VIS [1, 11]	loose	communicat-ion	yes	yes	yes	yes	yes	yes

3.1 Navigation Oriented Systems

The primary user task in Navigation Orientated System is to traverse the VE and browse the information space. Correspondingly, CVE design is focused on how to provide the virtual world representation, to navigate through the large space, and to support subjective view and collaborator awareness. We have selected seven CVEs within which user activity is mainly to walk or look around, occasionally chat and change the world appearance. They include three virtual society computer games [43, 46, 48], two documents browsing system [26] [47], an immersive learning environment [49] and a CVE [45] for geographic information visualization. Inspecting their approaches to the user related issues listed in our taxonomy matrix, we find that, among the surveyed systems, the VR-VIBE [26] does the most to address these issues while the GeoVISTA [45] does the least. When we compare the columns of the matrix, it is apparent that Navigation Orientated Systems provide stronger support for subject view, collaboration context and user awareness than user privacy protection.

Almost all the navigation oriented systems we inspect provide subjective view capability. Age of Empires [43], one of the popular virtual society computer games, provides a shared view of the 2D land map with subjective viewpoint support. The detail of a certain area is visible for a user only after he/she has explored to that point. By default, users are only able to see the few territories that are assigned to each player at the start of the game. In the AlphaWorld [46] virtual community, users can select different communities they hope to join in and explore and the system load in the corresponding world maps. Diamond Park [48] simple touring environment provides three view perspectives. They are the “bird-view”, “direct-view” and a “panoramic view” which is only enabled at the visitor’s starting point. Similar view perspective is provided in the Global Change World (GCW) virtual learning system. Users have an “over-the-shoulder view” and “outside view” (second-person view) of the 3D city model. The document browsing VE-VR-VIBE [26] uses different color and shapes to represent documents status of being viewed or changed and relevance to user current focus in each user’s subjective view. In Collaborative Information Spaces (CIS) [47], each user has a personal web browser interface that is projected to the real world background. The web-page content in the projected web browser can be subject to public or private view. For the VE background, users can see the real world using the see-through HMD. The only system that does not support subjective view is the GeoVISTA [45] geographic information visualization system. Although collaborators can focus on specific regions of the 2D geographic map the system does not provide different look of the map for simultaneous users. Users need to control their eyes for viewing different contents of the map that interest them.

For system navigation support, it is apparently that a large degree of navigation freedom is provided in this category of CVE. Age of Empire, AlphaWorld and GeoVISTA is based on 2D terrain map; hence the moving and zooming operation is supported. In particular AlphaWorld provides the LOD feature for map detail viewing. Diamond Park and GCW uses 3D immersive architecture VE. Users are allowed to view in 3D but travel only on the ground. In Diamond Park, there are pre-defined paths surrounding the Park artifact. In comparison, users can traverse in both spatial and temporal coordinates to see the effect of global climate changes in GCW. VR-VIBE provides a true 3D navigation capability such that users may travel in the whole space of documents. The system displays the 3D coordinates of user's position at any time. In CIS, collaboration is based on web pages on the World Wide Web. Users can navigate the web as they normally do in the real world. At the same time, user's mobility in the real world environment is guaranteed by the See-through HMD. A "Teleport" [46, 48] function is designed to switch user to remote VE points, such as a different virtual city, without foot walk. Through our study, we find that the issue of navigation support combined with user subject view support, are concentration of system design for the navigation oriented VE.

Users are given the ability to manipulate the VE look and feel, the interaction media and some objects in the scene. In Age of Empire, GeoVISTA and GCW, one of the user tasks is to change the world look and feel, by adding architectures and changing the environment parameters. The world structure is changed in VR-VIBE when users manipulate the documents content and position. On the other hand, the world structure is unmodifiable in CIS and Diamond Park. In Age of Empire and AlphaWorld, the appearance of user embodiment as virtual character in the game can be changed by users under the constraint of game rule while users can only choose the few avatars built by the system developers in the other five CVEs.

For the issue of privacy control, three aspects are inspected. They include the model protecting and access control in the user-VE interaction and privacy in the user-user interaction. Not all navigation oriented systems provide privacy control. The first three CVEs we analyze have model protecting for simultaneous user access. In Age of Empires, the statistics about an empire such as the land area and the number of soldiers is known only to the empire owner according to the game rule. The online community game Alpha World defines group access rules for objects owned by a virtual organization of people. Web page visibility can be controlled by users in CIS so that the user who initializes the page can make the page visible to all other or keep it private. Rest of the navigation oriented CVEs tend to promote collaboration and emphasize on resource sharing. Hence no model protecting mechanisms are given in them.

The system access control can be classified to three levels: per object, per session, and per system. If a CVE has model protecting over VE object, we consider it has "per object" access control. Otherwise, if the collaboration activity is same-time collaboration and can be stopped and restart in separate sessions, like in the Age of Empire and GCW, we denote it with "per session" access control. For the collaboration of different time and places, such as in the VR-VIBE, the VE is evolved over the time and there is no concept of "session". If such system requires password access, then access control is regarded as "per system".

User privacy in the user-user interaction mainly refers to user visibility and communication privacy. As indicated by table 1.1 b, most of the navigation oriented systems lack privacy design. AlphaWorld allows both public chatting and private message within a formed user group. Users can hide their online status and block incoming messages. In VR-VIBE, A notable feature is the user presence protection. When a user firstly enters the system, the embodiment is set to be invisible to others. However, privacy protection design may be extended to protect personal documents and notes as expected in real world. There can be two reasons for the lack of user interaction privacy control in some systems: no requirement specification and the cost of user privacy management. In CIS, privacy request is on the web page sharing rather than user embodiment protection. GCW is a two-person system, private communication channel would be unnecessary. In GeoVISTA, most user interaction occurs in the real world environment. Privacy can be obtained as it can in the real world. However, the communication overhead in providing separate voice talking for user groups can be substantial for network CVEs, such as the Age of Empire and Diamond Park, due to the cost of message multicast. Hence no private talking is supported by a few of such systems.

Most of the CVEs support loose synchronization of user activity. That is to update user modification to the VE according to the sequence of related system events. The update does not transmit to all user views immediately but the order of event cause and effect is guaranteed. Tight user action synchronization is established in GeoVISTA system. At any time, only one user can direct the collaboration and manipulate the 2D map. Other users' actions are queued up for later processing.

Realization of user awareness is crucial to the quality of collaboration. The content of awareness includes collaboration context and user presence, focus and interest. The basic context of collaboration is the time, location and history of the collaboration. Almost all the systems provide indication about collaboration time and space. System broadcasts messages about time elapse in Age of Empire, AlphaWorld and GeoVISTA. User position and direction are indicated by system coordinate or “compass” artifact. For CVEs with augmented reality feature, such as CIS and GeoVISTA, the real world is part of the VE. Therefore users are aware of each other and the temporal-spatial information in the VE. Usage history and past events are recorded and delivered on demand in some systems. In AlphWorld, system broadcasts import community events to all users. In GCW, users can traverse back in the history to see previous modifications and result. In VR-VIBE, notes can be left on document to keep users aware of the interaction context. User presence is represented by avatar embodiment. In Age of Empire game, players are aware of each other’s presence but individual focus and interest are protected according to the game rule. CIS attaches “gaze icon” to web pages to indicate viewer focus point. In Diamond Park, user awareness can be obtained through the real-time audio system that supports voice talk, background sounds and natural sound effect. Similar audio system is provided in GCW.

3.2 Communication and Negotiation Oriented Systems

The second category of our study is the Communication and Negotiation Orientated System, in which user interaction design concentrates on providing multi-user verbal or text contact facilities. A large percent of such system belongs to videoconference application. In contrast to the cheap, low quality PC-based videoconference tools, such as MSN and AOL Messenger, videoconference CVE system usually involves multiple audio/video channels for multi-directional communication. In particular, immersive virtual world filled with objects and user avatar will be constructed for improving the sense of co-presence in teleconference. We investigate six videoconference systems. They include the large display distributed network system Access Grid [20], which has the largest user base among all public teleconference systems. Greenspace I and II [50], a remote computer sharing application based on vedio conference; Face Mouse [51], an immersive 3D graphical CVE with text, audio and vedio communication function; MASSIVE (-1), MASSIVE-2, 3 [12, 52] virtual TV broadcasting environment with large audience, and the commercial web-based teleconferencing software NetMeeting [42]; one of the latest tele-presence system VIRTUE [53, 54] (Virtual Team User Environment) that utilizes the concept of mixed reality. The user awareness is the most significant issue for CVEs in this category. It has been concluded that the presence of speaker, their eye contact and focus plays a large role in conversational turn-taking [20]. For rest of the issues in our taxonomy, the privacy control issue is the next important. Secret attendance is sometimes preferred. While individual user may has the wish to whisper or talk secretly during a conference, most existing system do not support private communication channel due to the hardware complexity.

About half of the communication oriented CVEs do not support subjective view. The two systems that have subjective view support are Access Grid [20] and MASSIVE [12, 52]. Access Grid (AG) [20] is a multi-regional worldwide project aimed at developing large scale collaborative environment that allows audio and video conferencing. Users on an AG node can selectively view the window images of remote participants by opening or closing their windows. MASSIVE is an immersive distributed VR system that has been used for series of teleconferencing trials over wide area networks. Users are free to enter different virtual world connected by portals and have 10 types of subjective views, such as “over-the-shoulder” view and “bird view” on the world. In addition, NetMeeting [42] assigns separate windows to different user tasks: text-chatting, file sending, and whiteboard discussion. Users are able to choose the system feature they want by system configuration, which is a kind of subjective view of the VE.

For navigation support, systems that are designed primarily for teleconference application, such as the Access Grid and NetMeeting do not provide navigation capability for the virtual meeting environment. However, the NetMeeting supports discussion through a 2D white board which allows navigation. Three immersive CVEs, Greenspace [50], MASSIVE-1 [12], and MASSIVE-3 [52] support user traversal in the 3D VE. Face Mouse [51] allows user navigation in the 2D application GUI. A special situation is in VIRTUE [53], a semi-immersive CVE in which life-size 3D video images of remote users' upper body are projected to be surrounding a shared real table. The real world background becomes a part of the VE and users can move freely in it without functional support.

Various degree of manipulation freedom is observed. Four of the communication oriented systems support user specification of user avatar appearance. Collaborator images can be selected and attached to the mouse icons that represent the collaborators in Face Mouse. Also, individual participant can use each local mouse to control the placement of the face avatar. Similarly, in NetMeeting: on-line group conferencing system, user may choose image icons to represent their head avatar. In MASSIVE system, user capability such as text or verbal chatting is indicated by different avatar appearance. The communication oriented systems also provide support for object manipulation. For example, the CVE for an architectural design review in Greenspace- II [50] support replacement of architecture parts in the VRML world model. MASSIVE-3 allows user interaction with some simple objects on the stage for performing art show. VIRTUE provides choices of different shape of the meeting table. Users may sit face-to-face besides a long bench or surrounding a round-shaped table.

For the issue of privacy control through user-VE and user-user interaction, the design focus is on providing communication privacy for individuals and groups, and on protecting the shared files during the virtual conference. A large percent of the communication oriented systems do not have model protecting mechanism simply because collaborators do not need to share any common object but only the meeting space. In Access Grid, Participants from different places can connect to the AG node using common desktop computer. An AG node is the venue of a teleconference event on the network. It is password protected. In NetMeeting, the shared files can be viewed and transferred among a group of meeting attendants. Other NetMeeting users outside the group can not access the group resources. The system level access control for the communication oriented conferencing CVE is “per session” most times except in Access Grid. To create a large group meeting in Access Grid, user must specify a virtual meeting event on the AG and schedule AG node usage with the AG maintenance team. Hence the access control is on a “per node” basis.

Privacy in the user-user interaction is expected but not sufficiently addressed. Besides NetMeeting, none of the CVEs we investigate has provided private communication channel, although users generally require having selective communication with specific persons. In access grid, the image of a remote attendant and the real world background will be projected to the shared screen without any conservation. There is no way to hide user presence from the public in Access Grid, Greenspace, and MASSIVE-1,-3. NetMeeting provides a good example of user privacy protection. It allows users to hide their on-line status and appear to be off-line. Communication takes place within user groups that are managed by the NetMeeting system. User action policies that are compatible with user presence state are given. For example, on-line users who disguise themselves to be off-line are not allowed to speak unless they expose from hiding. This reduces the problem of unknown voice from hidden speakers.

Loose user action synchronization is prevalent in the communication oriented systems.

However in MASSIVE-1, only one user is allowed to speak at any time in order to synchronize multiple users' speaking over the shared verbal communication channel. Correspondingly, a mouse will be displayed on the avatar of a user who gets the permission to speak.

The issue of user awareness is settled comparably well in the communication oriented systems. For the semi-immersive CVEs: Access Grid and VIRTUE, user awareness to the time and space is not an issue since users are aware of the real world environment they reside in when they use the CVE. Access Grid users know that he/she is using remote connection with his/her desktop at home or gather in an AG meeting room somewhere. VIRTUE users understand the place of the virtual table they are standing by and where their collaborators come from. In the VRML modeling VE GreenSpace, users are not noticed about the time but they know of the VE place by different themes of the meeting room and the small room area they are allowed to traverse. The rest of the communication oriented CVEs all provide hint about the system time and space. In addition, MASSIVE-3 and NetMeeting systems have collaboration history record. User actions in the on-line art and performance game are recorded and can be replayed to retrieve collaboration history in MASSIVE-3. Users chatting messages and file operations are recorded as log file in NetMeeting.

User presence, focus and interest awareness are also addressed. All the seven communication oriented CVEs we investigate use either user avatar or projection of user body image to provide presence awareness. In particular, MASSIVE-1 uses the avatar body posture to indicate user presence. If a user temporarily leaves the VE, his/her avatar will lie down which means unable to chat. Five of the communication oriented CVEs have support for focus awareness and four of them support interest awareness. In Access Grid, the working environment of each remote user are projected onto the AG node large-screen display for sharing, collaborators can find each others' interest from the projected image of user activity. In Greenspace, user avatar is created with user facial scan image. Speech recognition tool is used for creating avatar facial expression to help promoting user awareness. Face mouse users can move their face avatars near an object so the rest of them will be awareness of who is interested at where. It thus attempts to overcome the problem that participants can not recognize to whom a presenting mouse belongs to when there are multiple mouse pointers in a whiteboard teleconference. MASSIVE-1 [12] system provides user avatar with different look for users with graphical, audio and text communication ability. For example, the T-shape avatar means text-only chat ability. In MASSIVE-3, user interest is recognized by the system built-in policies given in the SPLINE [30] architecture. It arbitrates which collection of environment aspects will be rendered for the specific participants. Users convey their interest by chatting and the shared white board in NetMeeting. The semi-immersive CVE: VIRTUE supports natural eye contact and verbal talking. Hence the focus and interest awareness is not an issue.

3.3 Object Manipulation Oriented Systems

Collaborative work environment is not limited to support navigation and communication activity. A major type of collaboration that drives the development of CVE is for multi-user problem analysis and task solving. In the collaborative problem analysis and solving scenario, such as collaborative architecture constructing or patient illness study, multiple participants focus closely on a few objects and interact frequently with each other through object manipulation. The result of user behavior is more complex than viewing and talking centered system. Object manipulation oriented CVE is designed for collaborative problem investigation. Our AMMP-VIS CVE belongs to this category. Requirements on the collaboration function focus on providing transparent object sharing for contemporary users, solving user action conflict and object ownership protection. The application systems we review are for solving specific problems. In particular, our AMMP-VIS system is designed for collaborative molecular modeling study. Collaboration function is designed to synchronize the frequent user-VE interaction and prevent user privacy violation. We have identified the major user issues through our user study and tried to learn lessons from the existing CVE design.

All the nine object manipulation oriented systems support subjective view. The numerical data visualization system CAVE6D [31] allows users to turn on / off visualization parameters in the shared global view or in one's own view. The similar function is observed in the DocShow [36] visualization CVE. COVISE [55] Users can select their interested airplane parts model in the viewing window of each user interface. In DEVA3 [56], a virtual object is comprised of a single "behavior" entity and several "look and feel" entities. User-definable policy will determine the object appearance in the subjective view. The MUVEES [13] CVE bears the feature of navigation oriented systems. Users traverse in the architecture themed environment are provided with a number of view styles over the world. In the military battlefield simulation system: NPSNET [44], the area is partitioned to fix-sized hexagonal cells which form IP-multicast groups. Entities that move around the battlefield receive information about the world, such as the world look and feel from the closest group in the neighborhood. SCAPE [57] provides a multi-perspective virtual interface. In addition, an exocentric "world miniature" view is supported by the augmented workbench device, which allows users to have an egocentric, high detailed "first person, life-sized" viewpoint on the large display. In the StudierStube [58] based virtual Mahjongg game [34], subjective view is enforced by the game rule such that the Mahjongg cards on a player's interaction panel can be viewed only by that player. AMMP-VIS molecular visualization system support different visualization styles for molecules. Collaborators can choose the style on individual client machines. The access control model and multiple session views developed in AMMP-EXTN offer more choices for subjective views. Users are allowed to participate in multiple sessions and see different collaboration contents. Their privilege of objects access will decide how much shared resources they can view.

Users are able to navigate in the 3D VE of the object manipulation oriented systems we inspect. In particular, the CVE with augmented reality support: SCAPE allows user avatars to travel in the augmented workbench according to the users' movement in the room-size immersive VE. AMMP-VIS provides navigation support in that users can explore the 3D visualization environment by moving their hand avatars.

Each of the object manipulation oriented support user interaction with at least one type of virtual object. For the three visualization systems: CAVE6D, AMMP-VIS and DocShow, CAVE6D allows user change of environment data model through parameter specification, and change the visualization accordingly. The data model is manipulated by user drag and move of the visualization in the AMMP-VIS CVE. DocShow has a web-browser plug-in viewer in which users are capable of steering the visualization and computation parameters for the 3D dynamic physical data. In MUVEES, students interact with digital building and natural resource artifact to analyze environmental and health problems. NPSNET users manipulate their own computers which are assigned the role of weapon or army men during the simulation. In the SCAPE, users can change their avatar location without actual traveling by manipulating their embodiment in the augmented workbench, which provide a "miniature view" of the VE. In the AR application StudierStube, users can adjust the virtual buttons, sliders displayed on the Personal Interaction Panel (PIP), a real world object that is integrated into the VE.

For the issue of privacy control, several systems propose strategies for modeling protecting. COVISE allows a user to select airplane parts model in the local viewing window, which is not visible to other collaborators. SCAPE provides multiple individual ownership or user group ownership of the same virtual objects. For the augmented artifacts of the CVE, such as the center hall, their virtual components are rendered only in their owners' view. The degree of object privacy expected by the game rule is implemented in the StudierStube based virtual Mahjongg game. Users can specify the information they want to hide, such as their card arrangement, from collaborators through their PIP. In AMMP-EXTN, object access rules are designed to regulate user access to the molecule data file and the visualization. More trustable users will be permitted to access more system resources while less trustable collaborators may be confined to view only the visualization image. Therefore AMMP-EXTN incorporates different levels of system access control in addition to the "per session" style access control used by many CVEs.

Very few systems in the category of object manipulation oriented CVE support privacy control for user-user interaction. MUVEES and AMMP-EXTN are the two systems we have found to support user communication privacy. MUVEES users are usually divided to small-size teams, each with two to four users. Communication is allowed within competing teams but the inner-team dialogue is only displayed to the team members. AMMP-EXTN has implemented a text chatting tools for collaborators and support multiple sides chatting for users within a collaborative session.

In coordinating the user action synchronization, DEVA3 system uses asynchronous system update. It is because one of the DEVA3 design goal is to achieve loose model synchronization with network limitation. When the world model changes, local region is immediately updated while the system slowly transmitting the update to rest of the network. Users do not need to wait for updates from each other's change. But enough local region updates will be provided to reduce visible anomaly. Rest of the systems use loose synchronization. In particular, the COVISE collaboration session allows priority specification of object control. Only one user (called "master") has the complete control over the environment while the others (called "slave") can only view the model unless they obtain the "master" role. Such constraints limit the collaboration range and user freedom. Compared to AMMP-EXTN design strategies, multiple users are allowed to interact with the shared model at the same time, but one "master" with the highest action priority is established in a session to control other participants' behavior.

User awareness issue is generally well addressed in the object manipulation oriented CVEs. Three systems provide user with the complete collaboration context (time, space and history). They are: CAVE6D, MUVEES and AMMP-VIS. CAVE6D produces a globally shared time dimension and individual space dimension. Users are aware of the collaboration time and space and can travel in both the time and space dimension. Similarly in MUVEES, users can travel back to the 19th century city and forward to the 21st century environment. The systems evolve a few months every time a user re-enter it. Collaboration history is indicated by the environment changes resulted from the user past activity. AMMP-VIS provides the 3D coordinates of the user hand avatar. In AMMP-EXTN, the duration of collaboration sessions can be found in the session information database. Molecule model changes made by user interaction are recorded to log files which are created for every collaborative session. Other CVEs give certain aspect of awareness supports. For example, the simulated battle field NPSNET provides information about time and space but no hint of the collaboration history. DEVA3 users only know of their location but none of the system time elapse and their action history. In DocShow, 3D-annotation can be attached to animated entities for retrieving collaboration context. Video records are generated to store and replay session, which helps to provide clue of collaboration history.

The awareness to user presence, focus and interest is also handled. All the object manipulation oriented systems create user avatars for presence awareness except in StudierStube CVE, where users can see each other in real world due to the AR feature. Many systems also supports user focus and interest awareness. In CAVE6D, user hand avatar is able to manipulate long pointing-rays for focus expression. COVISE provides a zoomable view window so that users can focus on the model part their collaborators are interested in. MUVEES users can show "snapshots" from their current view point to indicate their focus of interest. User focus and interest can be communicated with the system communication support. NPSNET has concerns on user interest management. In StudierStube, user focus and interest can be perceived as users see each other in the real world background. In DocShow, teleconference software is used to communicate facial expression and voice among teachers, audience and students. Tele-pointers are shared to transfer gesture and pointing. In AMMP-VIS, user hand avatar designates user presence. In addition, the collaborators information is available in the AMMP-EXTN session database. Users can define bounding box on the molecule models to indicate their focus area. Communication tool helps user to articulate their interest.

CHAPTER 4: AMMP-EXTN CVE Collaboration Improvement

This Chapter describes and analyzes our development of collaboration and utility functions for improving the usability of the molecular modeling CVE system AMMP-VIS. The new functional modules address the high level user issues in the aspect of user access control, priority management, subjective views as well as collaborator management and user awareness. Our design is based on the user feedback of the AMMP-VIS system. Like many 3D immersive CVE, AMMP-VIS has the advantage of immersive look and feel and can support natural user interaction. However, AMMP-VIS also manifests the problems of immersive CVE: command invocation appears indirect and user awareness is weak. We propose AMMP-EXTN in an effort to combine the experience of immersive CVE with the easiness of user control in the 2D interface and provide user with the flexibility of transport between the 3D world view and 2D control window. We hope to set a model for handling collaborative molecular modeling activity in CVE.

4.1 Brief overview of recent collaborative visualization systems for molecular modeling

Molecular visualization process consists of displaying protein structures and vibration, electron density map, and computing molecular dynamics. It is widely used in molecular study and research which usually involve a group of domain-specific users. Hence developing collaborative visualization system for molecular modeling has a significant benefit. A great deal of design efforts have been made to build visualization tools and data representation for molecular. Effort is also spent on developing the distributed architecture to support remote collaboration and interaction. Nowadays, individual with PC running the collaborative molecular visualization software is able to connect to the collaboration server to access the shared data and participate in the joint visualization process. A number of visualization systems have been developed to provide the collaborative working environment. There are three systems, Pauling World [10], JMol [9] and Chimera [8], which are designed for collaborative molecular visualization.

PaulingWorld [10] is a distributed VR application designed to support collaborative remote learning. It provides large molecule visualization in an immersive CAVE like environment. A number of molecule representations are supported, such as ball and stick, wire frame and space filling model. In particular, repetitive structures are depicted as icons at first to save display space. Another advantage of PaulingWorld is the capability for real time collaboration over long distances. However, special hardware is required to use this CVE. It only runs on SGI computers, which connected to immersive CAVE system, collaborative workbenches and head mounted display.

Alternatively, the Jmol molecule visualization program [9] is a web browser based, peer to peer system using a Sun's java P2P networking framework API (JXTA). The open source molecular modeling toolkit JMol provides molecular manipulation functions as well as structure measurement in a 2D GUI without collaborative function. The CVE developer inserts JXTA P2P service code into the JMol event handler to transmit modeling changes from one peer to another. The P2P architecture can solve the problem of single failure point in the CS (Client/Server) system. However, it induces the communication overhead when updating messages are sent among the peers. A distributed database is still in construction for their P2P network model in which each peer keeps a copy of all data files.

Chimera [8] is another 2D collaborative molecular visualization system. It includes a number of molecule analysis and visualization algorithms, such as molecular density maps and microscopy data visualization, multiple sequence alignment and multi-scale models. The collaboratary function is an extension to the single user system such that distant client computers can communicate with the Chimera server site and join collaboration session over standard network connection. Collaborators in a session share the WISIWYS interface with equal control over the molecular structures.

The goal of our AMMP-VIS [1] molecule modeling system is to provide an interactive and immersive visualization environment for real time collaboration. It works in the following manner. Molecular structure files which specify the position and topology of atoms and bonds are read into our system as raw data. The system performs a 3D mapping of the atom position to the graphic space and renders the structure with the traditional “ball and stick” style. After this initial visualization, the control is given to user for filtering structure data and specifying viewing parameters. AMMP-VIS provides a variety of visualization controls as well as real time collaborative manipulation function.

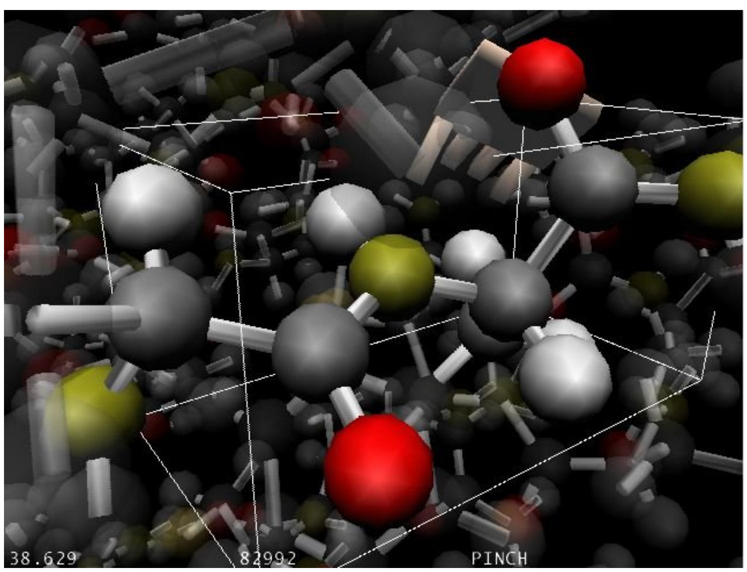


Figure 4-1. The single shared view in AMMP molecule modeling CVR

Figure 4-1 illustrates a modeling scene in AMMP-VIS. The system allows a collaborator to specify focus area with a bounding box in which he/she can have exclusive control over the shared atoms in the collaboration view. Being an immersive VR system, AMMP-VIS supports natural hand object interaction such that user can hold and drag the 3D molecule model given a HMD and haptic devices such as data glove and joystick.

Collaborative modeling in AMMP-VIS takes a “remote” style. Scientists run the AMMP-VIS client side program on their local computers and connect to the AMMP-VIS collaboration server for sharing a collaboration view. The server exchanges user communication message, update molecule structure change according to user manipulation and manages access control. To start a collaborative modeling session, user’s local computer needs to upload molecule structure file to the server, which keeps updating the file during the collaboration. The modeling result as a new structure file and a modeling log can be saved back to collaborators’ local machine after the session finishes.

With respect to the taxonomy matrix we proposed in Chapter 3, all these four CVEs support subjective view and certain level of user awareness. On the other hand, no evidence can be found in any of these systems for their attention to other important user issues including user privacy protection, collaboration context retrieval and workspace transition. In the design of AMMP-EXTN CVE, an extension to the AMMP-VIS system, we try to investigate the manifestation of these issues in the specific collaborative work scenario and propose our solution. The following sections detail our work.

4.2 Privacy control on the Data Model and Modeling

Our first goal is to address the problem of user privacy protection in the shared view and collaborative modeling. This problem relates to VR access control issue which can be handled by the existing process synchronization technique. Under the access control framework defined by [28], simultaneous access on shared object, event and process will follow a sequential event order inside the system and therefore avoid conflicting result. In case of user privacy control, access refers to the right to use resources owned or maintained by individual or a participating group of the collaboration. It is possible that in any group work situation, people try to share information and experience while keep some knowledge known only within a certain clique. Such knowledge ranges from user belongings, personal communication, and activity to even the person's appearance.

In systems we reviewed in the previous chapter, telecommunication application [42] usually has the ability to provide both public and private talking channels. Encrypted message can be transferred among selected peers. The on-line community game CVE [32] allows personal information, such as user name and skill level to be hidden. Access to individual possession is controlled similar to the file access control in operating system. Of the few collaborative visualization systems which provide privacy protection function, the StudierStube [58] most closely emulate the real world situation. A Mahjongg game player in the StudierStube CVE is able to see only his/her card and the card detail will remain invisible until it is placed onto the player shared table.

In addition, controlling visibility of proprietary objects, user status, user actions and user presentation in the VR is a major part of privacy protection. The Subjective VR-VIBE [26], for example, keeps user embodiments in the scene only visible to their selected collaborators. This approach can avoid visual clutter as well as make user presence secrete.

AMMP-Vis is an object manipulation-oriented system. As discussed in chapter 3, such type of system is designed for collaborative problem solving and user behavior pattern tends to be more complex than systems for the purpose of navigation and communication. In the process of molecular modeling for example, researchers who want to fit a model to its computed electronic density map will need to adjust the model structure and placement back and forth, using composite modeling commands. If a collaborator happens to tumble the model it may be very hard to restore the correct modeling result. Even worse, if researchers rely on their result for publication or making discovery, the negative impact is severe. On another occasion, a researcher only wants to show the visualization image to other collaborators but not the molecule data file he/she has. Hence it is vital to protect user privacy on objects subject to collaborative manipulation and destructive changes.

Compare to the privacy control in StudierStube [58] which is a distributed application, AMMP CVE is based on Client/Server architecture and therefore can not support different user specification of object visibility and sharing property for the same object. In our work, we define access control rules for the molecule modeling server for every collaboration session. Certain access priority can be established so that the user who claims ownership is able to deny others' access to her resources [11]. The object owner can also restore object to a previous state after her collaborator has made unwanted changes.

The collaboration extension of AMMP, AMMP-VIS-EXTN supports multiple parallel modeling sessions, in which different collaboration processes is performed and different levels of access control and action priority can be specified. We have modified the classification of access control proposed by Manssour and Freitas [59] and define new control rules for better addressing the need of researchers. Our access control object will be the molecule data file, modeling process, visualization parameter, and result image since these items will often be involved in ownership dispute when user privacy issue arises. For controlling the collaborator's simultaneous object access, we define different action priority for collaborators in a session. The content of action priority will be explained in the next section.

Table 4-1. Four levels of access control to molecule data and modeling process

Access To / User Access Level	Visualization Image	Mapping & Rendering Parameter	Interactive Molecule modeling	Molecule Data File
No Ctrl.	No	No	No	No
Viewing Ctrl.	Yes	Yes	No	No
Manipulation Ctrl.	Yes	Yes	Yes	No
Data Ctrl.	Yes	Yes	Yes	Yes

We define a four levels access control framework for molecule data and visualization process (Table 4-1.) Collaborator's access privilege increases through "no control" to "data control", provided with the ability to manipulate visualization components ranging from the image to the data file. The first level is for a none-collaborative process, which takes place on a local single-user session. All resources will be kept private and the system blocks any access attempt from the remote users. Hence it is called "*no control*" for potential collaborators. The second level "*Viewing control*" is similar to Manssour's [59] Local Control. That is, participants are allowed to view the visualization result as well as to customize a few viewing parameters such as the geometric primitive for atoms and lighting effect. Such view changes will not affect the modeling process and molecule files. They only change the visual appearance of model on a client machine. Users with viewing control are passive audience of the collaboration activity. In the third level, "*Manipulation Control*", collaborators gain further control on the modeling. Access to the modeling process means that users can directly interact with the model by dragging and rotating it and see the result of the real time dynamic energy field simulation. This is the general access level that collaborators will expect in order to truly participate in the collaboration. Users who can share the modeling have at least the chance to know about the part of the molecule structure they interact with, if they are not allowed to see the data file. The system can generate modeling action log files to help user review. The right to access and change the data file is only permitted in the last level of our access control framework, which is called "*Data Control*". The access to data file is given the strictest control because the content of a molecule structure described in the file is often claimed to be the discovery work of certain people in the real world research practice.

4.3 Designing Multiple View and Action Priority

In order to better support collaboration and accommodate larger numbers of participants, the single shared view of AMMP-VIS is replaced by a multiple view of parallel modeling sessions in AMMP-EXTN. Users may access multiple collaboration processes at the same time and take action in one of these processes, being in an immersive virtual world. A user is allowed to shift the current view among these simultaneous sessions. The design of multiple simultaneous sessions has added complexity to collaboration session management. To free up network bandwidth, we may need to force a user to log out a collaborative session if that user is currently active in another session. We also try to design different user avatars for active and non-active users in a session.

Most multi-session collaboration applications such as on-line chatting rooms allow user to engage in one session at a time for the sake of simplifying management. However, this limits users' knowledge of all the collaboration work that may interest them. Instead, if users are allowed to participate in multiple rooms at the same time, they are more flexible in their collaboration choices and less possible to be idle. Using multiple collaboration session simultaneously in multiple views helps to promote user collaboration initiative and chances to bring together collaborators with common interest and relevant skills. There are other advantages for designing multiple simultaneous shared views. For molecular modeling, allowing researchers to participate in multiple modeling processes at the same time can help them analyze and compare similar structures rendered in multiple views.

We allow each user on a client computer to participate in at most four simultaneous sessions in AMMP-EXTN. To ensure the system availability, different level of resource access is enforced. A user is able to create one "mastering" collaborative modeling session, one private local session and attend two other collaborative sessions with limited access to the session resource. In a "mastering" session, the user who creates it becomes the session "master" and he/she is given the ownership over the whole modeling process, the related molecule data and collaboration result. Other none-master users who enter the session later can view the visualization result at first and request access to other resources from the master. Different access privileges are assigned to the collaborators based on the access control framework we proposed in the previous section. Session master can prevent other users from altering the data by lowering a user's access privilege. However, the none-master users may be given higher access right once they become trusted by the master. The role of master is not permanent -- the initial session creator may transfer the master privilege to another collaborator so that one and only one user is the master of the session.

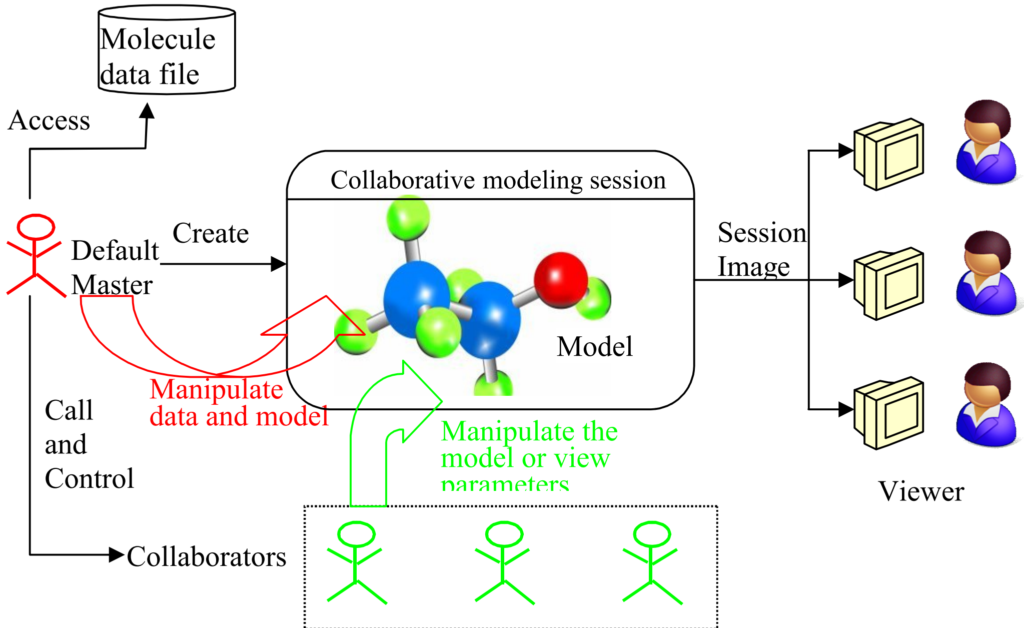


Figure 4-2. “Master” and the collaboration participants illustration

None-master users have either “Viewing control” or “Manipulation control”. For the former, visualization system simply transmits the image of the modeling process to the client side according to viewer’s specification on visualization parameter. For the latter, molecule data is encrypted before transmission and kept in the memory space known only to the AMMP system. To make the data file unreadable for limited users, we encrypted the file with server generated keys and remove it from the collaborator’s machine when collaboration finishes. The figure below shows the look of a shared-view collaborative modeling session from a master user’s perspective. For collaborators with only “Viewing” or “Manipulation” control, certain functions are disabled, and as a result some buttons of the interface, such as some “file” and “user” management commands, are grayed out.

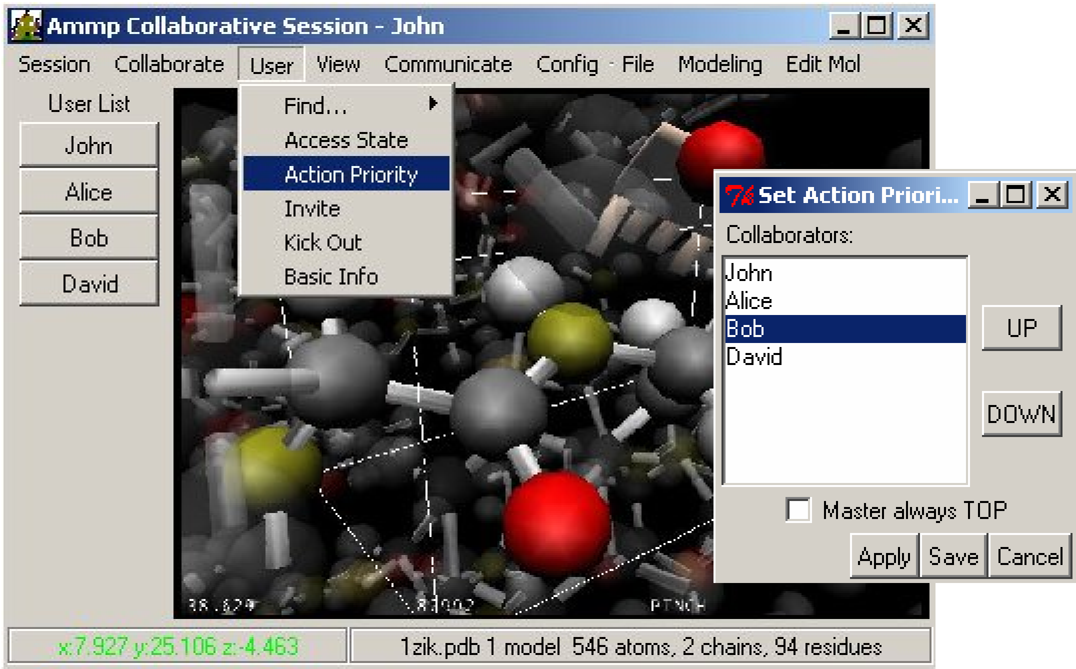


Figure 4-3. Defining Action Priority in the shared view of a collaborative modeling session

For users on the same access level, operation priority is further defined to manage simultaneous manipulations. A session creator (master) is given the highest priority over shared objects and is allowed to specify priority for other collaborators at any time during the session. Action priority in AMMP-VIS means that if two users have selected parts of the molecule model in the shared view respectively for manipulation, and the two parts overlap, the selection made by the lower priority user will be overridden by the higher priority user's selection. User action priority definition is useful to resolve the conflict when two collaborators try to move the molecule in opposite direction. Apparently, it will be effective to let the more experienced user obtain higher action priority. Thus, if a session creator has discovered a certain molecular structure which he/she wants to record or perhaps keep secrete during the collaboration, she can "lock" the object to prevent further changes from lower priority collaborators and save it to the local machine, which is protected by implementing the access control rule.

4.4 Managing Selective Collaboration and Communication

Another focus of our AMMP-EXTN development is to support selective collaboration among a large group of collaborators. One side of selective collaboration means that a user can assign different levels of access priority to her collaborators working on shared resource that she owns. The other side is the capability of searching collaborators, joining collaboration group and forming communication within the selected group. This requires the system to give user and session information when requested and provide exclusive communication channel for each collaboration group.

We have developed some communication functions similar to those in a text-based network Instant Message Tool. These functions enable message broadcasting and text-based chatting among a group of users (Figure 4-4). A typical scenario for broadcasting is after a user creates a collaboration session. Broadcasting messages can be sent by system to all current users for inviting collaborators (Figure 4), if the session is public. Our system also defines several default broadcasting events. For example, if a session master closes her session before all her collaborators exit, the system will broadcast a notice message to other collaborators saying that the session will be closed. During a collaborative modeling session, system maintains a collaborator list and allows those collaborators to chat with multiple partners.

Users other than the session master can also benefit from the selective collaboration functionality. In our system, they are allowed to view all session status (Figure 4-6.) and choose to join one of the collaboration groups. When participating in a collaboration process, they can request to change action priority or even to be the “master” (see Figure 4 “Collaborate” menu), who has the full control of the session access, group formation and action priority. If the user stays inactive for a long time in a session in which he/she has "manipulation" or "view" control -- the user may be actively working in another simultaneous session -- the system will warn the user for his/her idleness. Long idle collaborators should be logged out of a session by the system to save system resources.

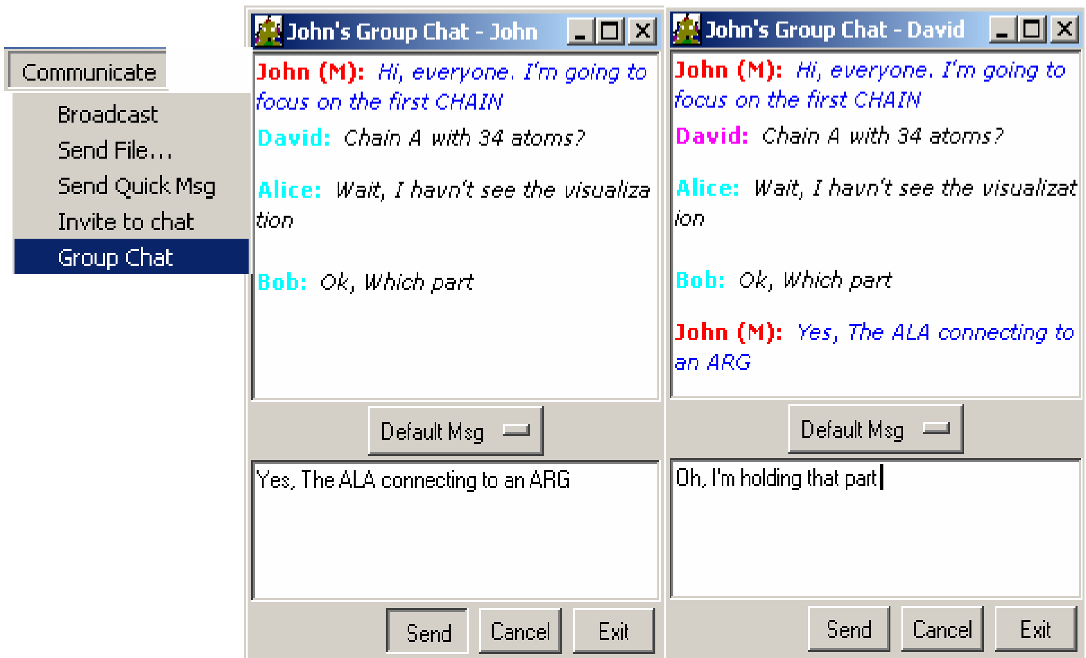


Figure 4-4. Text chat command invocation and dialog between two collaborators

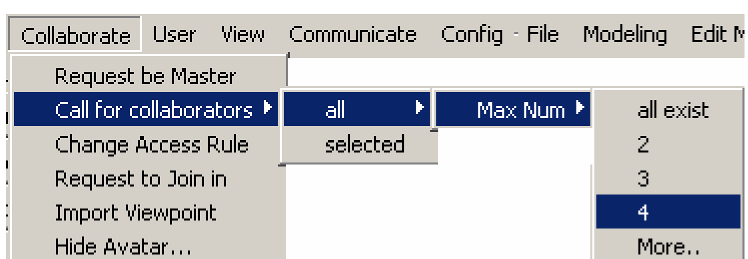


Figure 4-5. Session master broadcasting "solicit collaborator" calls

From Figure 4-5 we can observe several other very useful collaboration management functions. "Import Viewpoint" command allows a collaborator to use another user's view point. This helps to improve user's focus awareness, otherwise it is hard to express or find out where exactly a user is looking at on a large complex molecule model. The user can save his/her viewpoint by command under the "View" menu and shift back to his original viewpoint through "Import Viewpoint". "Hide Avatar" command can hide user's hand embodiment when a user hopes to perform some secret action or temporarily leave the session, or stay inactive.

Although it is more convenient to communicate by voice in an immersive molecular modeling CVR, building exclusive communication channel for special collaborator groups tends to be more complex, both in terms of the design and in user control. Moreover, voice communication will take up essential network bandwidth, thus leaving less resources for transmitting the large number of control and modeling parameters or the screen images.

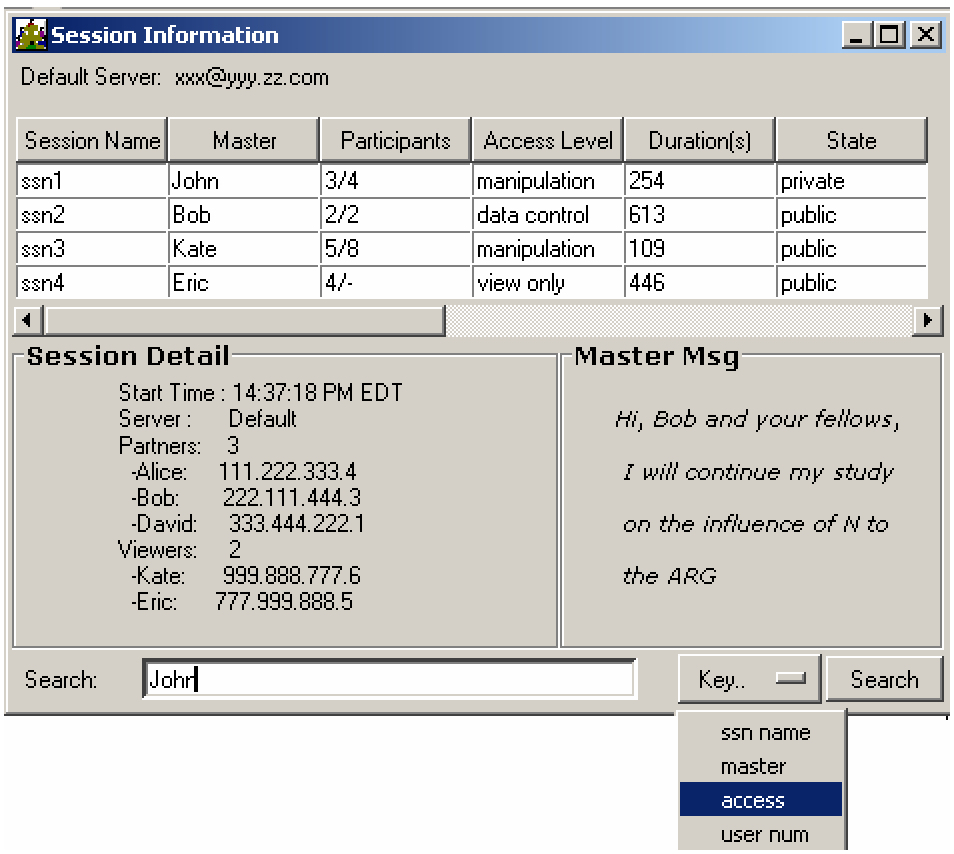


Figure 4-6. View session status command and result

A "world shift" button is designed to enable user to switch among the multiple simultaneous session. The button is visible in both the 2D control interface and the 3D immersive view. When a user is immersed in one session and hope to transfer to the other simultaneous session, he/she can use the button to return to the desktop 2D environment first, then move focus to the other session window, and finally, use the "world shift" button again in that window to join the new session. The "world shift" function helps user to go back to the control interface and issue command from the GUI. It also helps user to switch between their collaboration environment and private session.

CHAPTER 5: IMPLEMENTATION OF AMMP-EXTN CVE

The AMMP-EXTN system for enhanced remote collaboration is an application built upon our AMMP-VIS dynamic molecule modeling system. It supports all the molecule visualization features and a basic WYSIWYG shared view collaboration interface in AMMP-VIS. The client program is written in Python and C++. A Python GUI interface has been developed to wrap the function call and group related commands into a command menu. The collaboration system consists of a server, which maintains collaborative session, and several client machines, which run AMMP-EXTN client visualization program. Currently the client side program is implemented on the Windows platform.

5.1 Modeling Session Implementation

Our AMMP-EXTN defines every modeling process to be a "session", which contains visualization parameters, molecule model status as well as user and control information. A "single" session is created only on a user's local computer with no connection to the server. On the other hand, a "Collaborative" session is initialized by one user and maintained by the AMMP-VIS server. Figure 5-1 shows the configuration page when a new collaborative modeling session is created. A "private" session requires password for access.

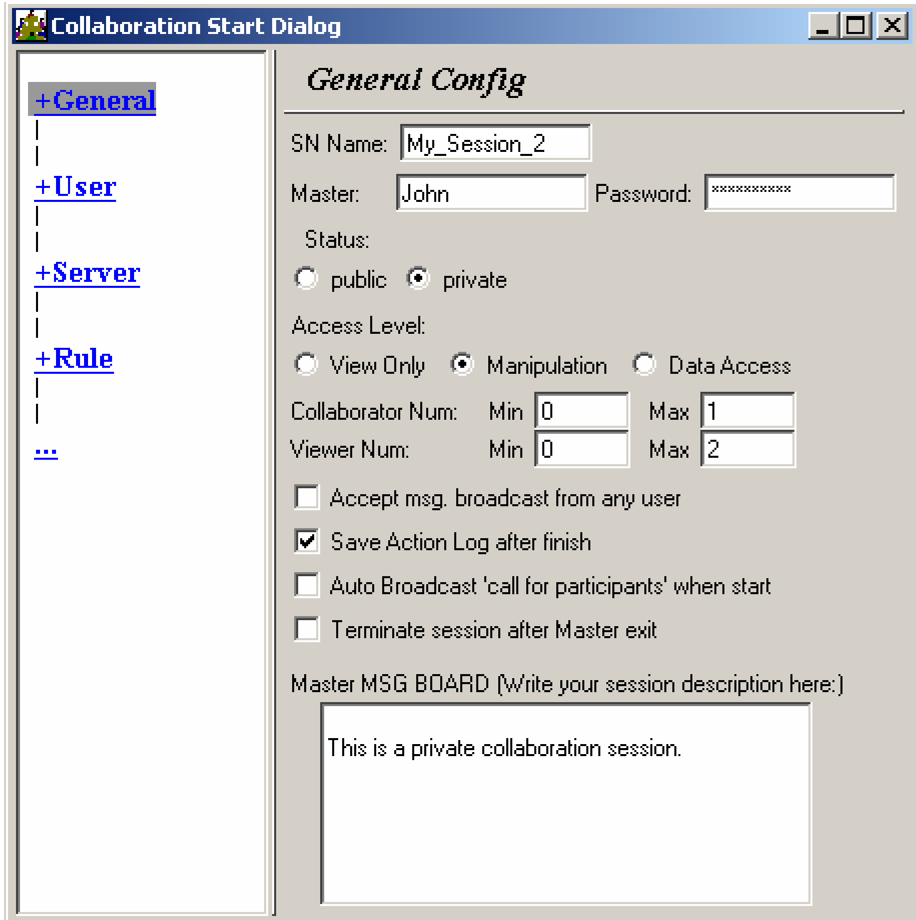


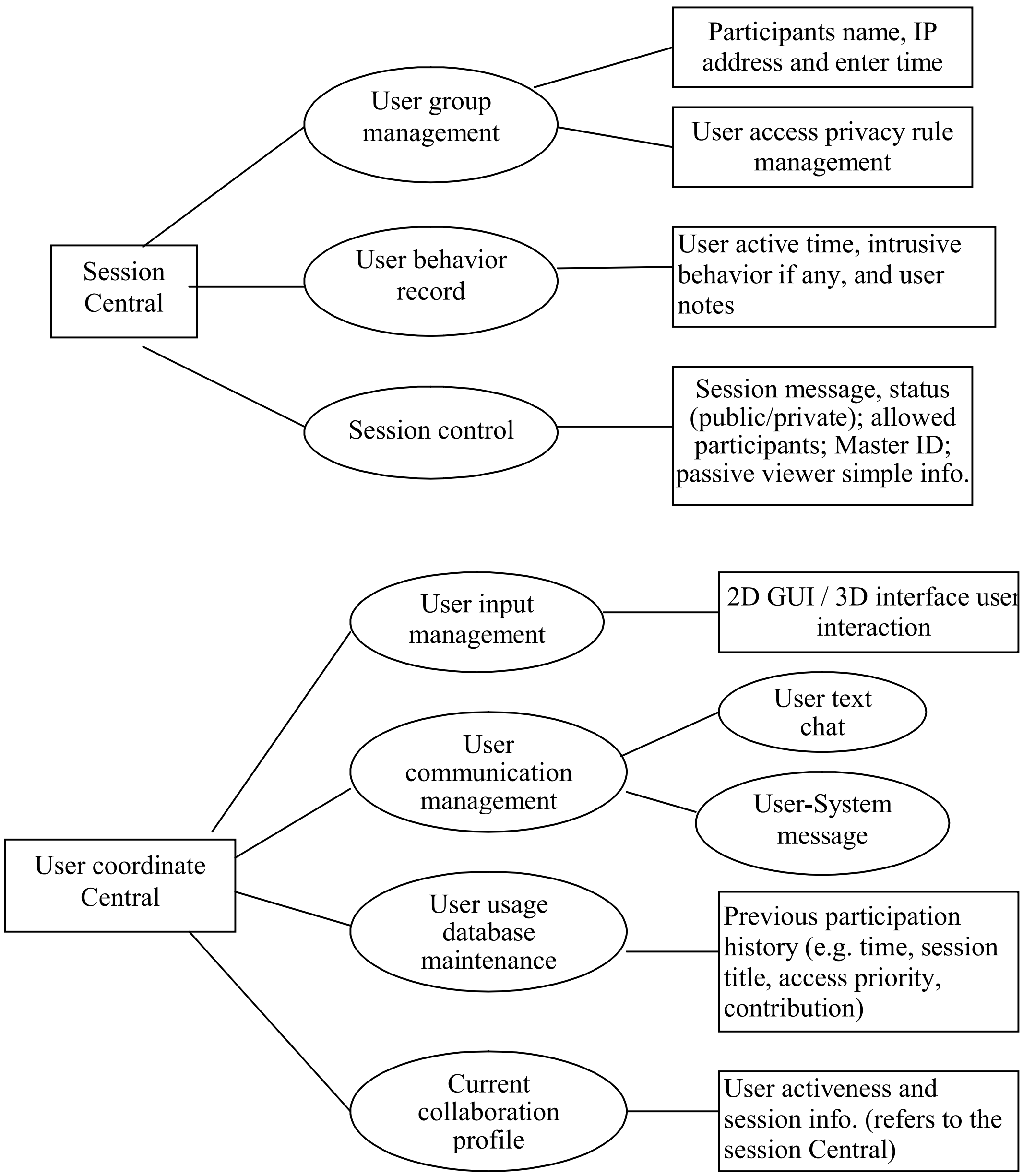
Figure 5-1: Collaborative modeling session configuration dialog

If a user chooses to create a "single" session and later on, hopes to make it "collaborative", he/she can choose to publish the session, uploading the molecule file and session status from the local machine to the server. On the other hand, if a session master hopes to do some private work and change the collaborative session to be "single", he/she can save the session back to local machine. When this happens or when the collaborative session terminates, the session participants can save what has been done into a session record. Depending on each participant's session access level, they may be allowed to save only the general information about the session, the modeling log file, or even a copy of the molecule data file.

Each of the multiple simultaneous sessions is associated with one modeling view (window). Each user can join or leave a collaborative session at any time. Currently, AMMP-EXTN only allows user to open one "single" session, one "master" or "manipulation control" collaborative session and less than two viewing sessions at the same time (see Figure 5-2). The purpose of this restriction is to simplify the session control and limit excessive bandwidth usage that may occur when a single client opens too many sessions. A user may be logged out from a session by the system due to his/ her low activeness and a session may be forced to close if all participants are inactive. The "world shift" button is placed inside the VR modeling window to enable user transition between the 3D visualization and 2D GUI, and among different session windows. To press the button, a user first moves the mouse or hand avatar onto it when working interactively in the 3D modeling VE.

5.2 The Collaboration Central

The Central refers to the AMMP-EXTN collaboration management unit in our server/client architecture. In AMMP-VIS system, an "orientation server" is set up to update client-side user data. Most of user data are the visualization parameters such as user viewpoint value and the hand avatar position. With multiple sessions and more active collaboration, more user data need to be transferred among server and the clients. Therefore, we have subdivided the AMMP-VIS "orientation server" into multiple administrative unites, called Central. Each Central is in charge of part of the collaboration function. We design a session Central, a user coordination Central, and a modeling Central in replace of the orientation server. The idea is that closely related information is managed by one Central, which can be deployed on a computer separated from the server machine. The distribution of central functions to separate computers can alleviate the work load of the single server. The following diagram illustrates the functionality structure of the AMMP-EXTN centrals.



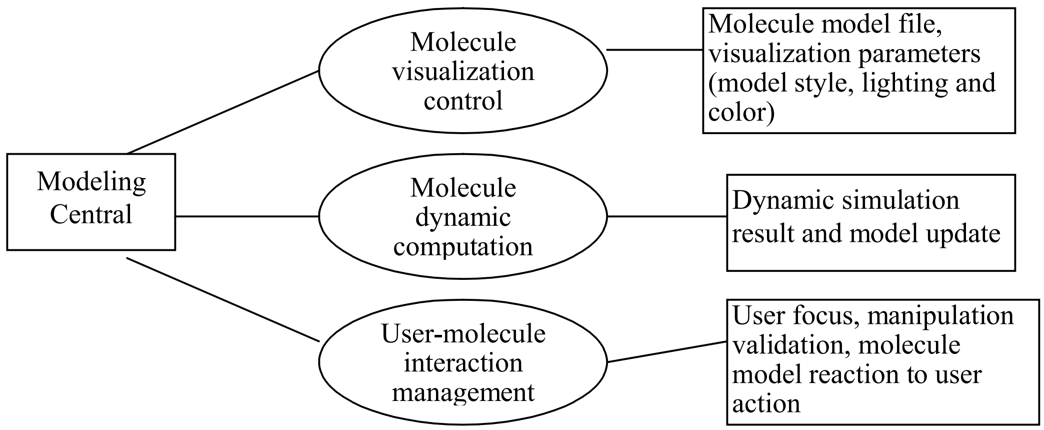


Figure 5-2: AMMP-EXTN server Central functionality deployment

The names of the major functions are written in oval boxes and the data managed or maintained by those functions are written in rectangular boxes. The Session Central is mainly responsible for the collaboration session control. In addition, user information is also managed by the Session Central. For every active collaboration session, the Session Central keeps a table of collaboration parameters, including access privacy and action priority for each participant. When a user tries to know his/her collaborators information in a specific session, the User coordination Central contacts the Session Central and retrieves all the necessary information at once from the user parameter table. Alternatively, we can design one table per user on the User Central to store user related information of all the sessions that a certain user participates in. However, the collaboration related search and management is frequently performed on a group of session users. It will be more efficient to aggregate user information based on each session in stead of gathering session information based on individual users. Therefore, we deploy the user group management function on the Session Central. For every user, the User Central only needs to record the number and IDs of the simultaneous sessions that the user works in so that it can refer to the Session Central for detailed information.

User coordinate Central is composed of four parts. The input management receives user command on the 2D control interface or keyboard input to the 3D modeling interface. The communication module manages the user text chatting and system messages generated by user commands. When a session is finished, the user related information will be extracted and added to the usage database for each user on the User Central. This database contains usage history for each user. The last component -- current collaboration profiling function -- keeps a list of the simultaneous sessions that a user has requested to participate in. For each session, the profiling keeps a reference to the session instance on the Session Central, from which details of any user session can be retrieved. Such session reference data structure eliminates duplication of session data on the User Central and is appropriate for monitoring the user's activeness.

The Modeling Central deals with the molecule visualization process. It handles the molecule rendering, user-molecule interaction and the dynamic energy field simulation. In the previous AMMP-VIS system, molecule file is transmitted to every collaborative client and rendered on the local machine. Every collaborator has the same shared view. In the AMMP-EXTN, a user may have limited access to the resources used in the collaborative session. Depending on whether a collaborator can interact with the model, the Modeling Central will forward the molecule file from server to the client computer and thus visualize the model locally. For passive viewers, only the screenshot of modeling process will be delivered by the server with pre-defined frame rate. For users with Manipulation Control but no file access privilege, the Modeling Central program on the server will dynamically encrypt the data file before transferring it to the client. Consequently, no other user but the client-side visualization program knows the content of molecule data, which will be deleted from the client machine when the collaboration ends.

Figure 5-3 gives an example of interactions among the three collaboration Centrals. The scenario depicts the Central communication and behavior when a user requests to join a collaborative session. User Central first checks the session status, such as whether it is a public or private session and the maximum number of users it accepts from the Session Central. If the user is accepted into the session, User Central needs to create a reference to this session in the current user profile and broadcasts a “new collaborator arrival” message to other users in that session. At the same time, the User Central updates the session related property of the new user to the Session Central collaboration table. After this, User Central contacts the Modeling Central for molecule data and resources. The Modeling Central needs to verify the user’s access right and action priority with the Session Central before it can send the model file or visualization image to the User Central on the client computer. After the initiation of the collaborative view, Modeling related user information is transferred constantly between the User and Modeling Central for user embodiment visualization and model manipulation.

Not all Collaboration Central modules are deployed on the AMMP-EXTN server. As we can see from the arrangement of their functionalities, User Central that deals with user input and messages must collect data from each client side. User agents, which are parts of the User Central are deployed on each client system to manage different type of user input data. The local visualization function that belongs to the Modeling Central is also implemented in the client program. AMMP-EXTN server mainly takes charge of the session Central.

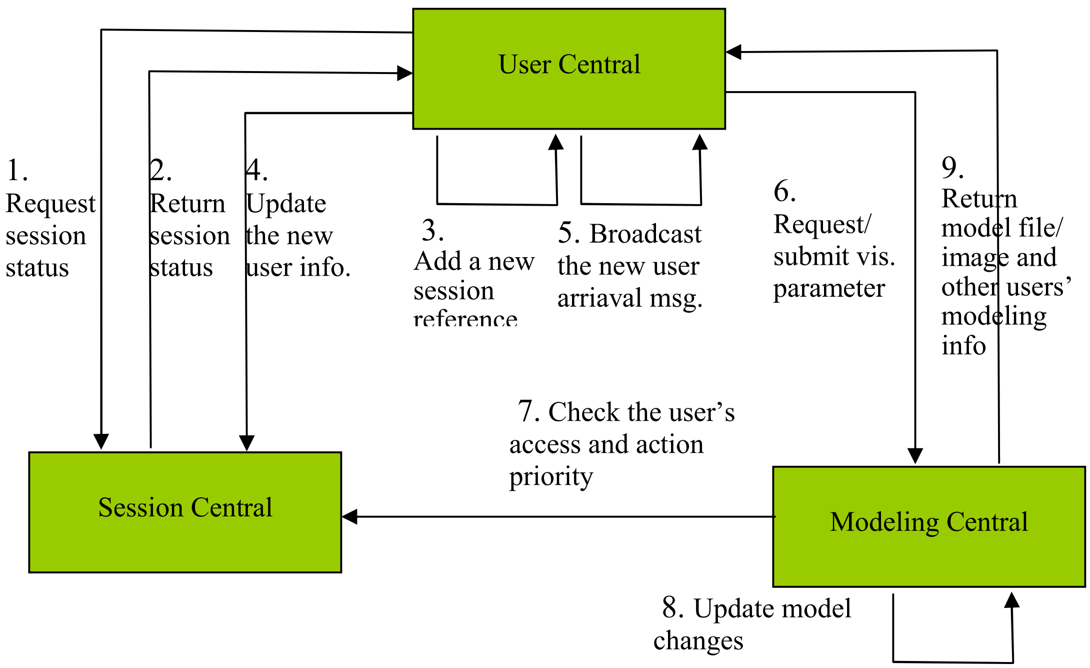


Figure 5-3: A collaboration Central interaction scenario

5.3 2D Control Interface

One of the major improvements to AMMP-VIS is the specification of system control function and user command and the implementation of a 2D control GUI that interacts with the user input and the system process. The control GUI offers user a complete set of user command tools. This has helped reduce users' memory load to remember complex keyboard shortcut for command invocation. It also reduces the need for 3D menu in the immersive 3D VR, which is hard to manipulate using hand avatar.

We implement the AMMP-EXTN control GUI with a graphic utility in Python language-TKinter [2]. It is a wrapper of the Tcl/TK graphic library. In Python program, the TK graphic function can be used by import the TKinter toolkit. Python is an easy-to-use object-oriented scripting language [59]. The advantage of scripting language is that the program is interpreted command by command, and it tends to be more readable and easier to debug than compiling languages. The downside of the scripting language is that the scripts may execute slowly and consume more memory.

Therefore, we enhance the core part of AMMP-VIS -- molecule visualization (implemented with OpenGL) and data input/ output (implemented with C++) -- with user information management and collaboration control module (implemented with Python). It is not hard for the Python GUI to access the C++ layer objects since the objects, such as molecule model, viewing style and clipping plane can be referred to equivalently in Python. Compared with Chimera [8], our control function does not provide as many molecule description and structure analysis tools. However, our focus is on the better management of user behavior in a collaborative working environment. As a result, user group management, user access and session control are readily available through the menus on the control interface. Access to multiple sessions has been achieved for every user in a highly organized manner (Figure 5-4).

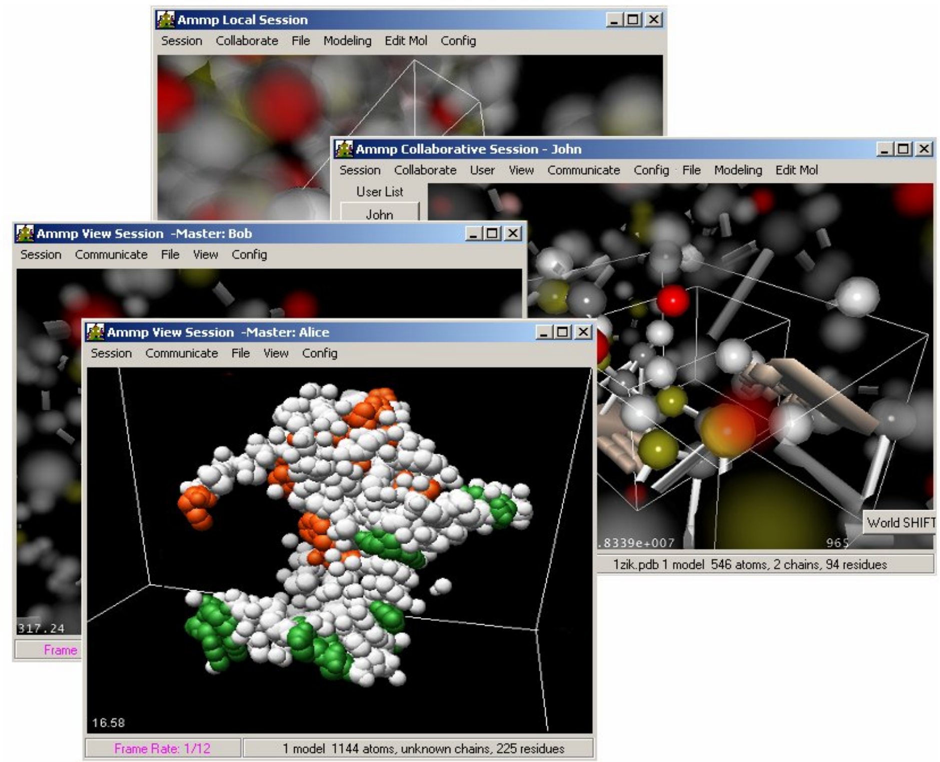


Figure 5-4: Simultaneous access to multiple sessions on a client machine

CHAPTER 6: AMMP-EXTN USER CENTERED EVALUATION

The aim of our system evaluation is to identify the usability problem by investigating the collaboration task, the 2D and 3D UI and human behavior aspects that affect user satisfaction and task performance. A number of methods have been proposed for assessing the system responsiveness, network configuration and scalability [60]. Yet little effort has been made to enrich the knowledge about the structured evaluation of CVE usability as well as usefulness. As a result, this lack of VE-specific usability tools and guidelines has created substantial difficulty for usability studies. To cope with this difficulty, we conducted an empirical evaluation of the AMMP-EXTN.

Our investigation concentrates on the task performance of user-centered interaction in the 3D immersive collaboration and the 2D control GUI. Our evaluation is guided by the following three observations:

1. Existing HCI design and evaluation methods for 2D applications needs to be adapted to 3D/ CVE applications.
2. It is difficult to form expectation of user behavior at the beginning of the system design. Therefore CVE-specific design strategy derived from this expectation needs to be searched, tested, and refined to ensure that user intention through their interactions with the CVE is recognized and properly handled.
3. The limitation of hardware technology and deployment, such as limited field of view, heavy tracking devices and the lack of haptic feedback should be separated from the software development flaw. This is because our evaluation is targeted at the software design aspect of AMMP-VIS, we try to identify issues stem from the software system.

We have attempted to use existing VR evaluation methods when necessary and incorporate the evaluation process through the AMMP-EXTN design cycle.

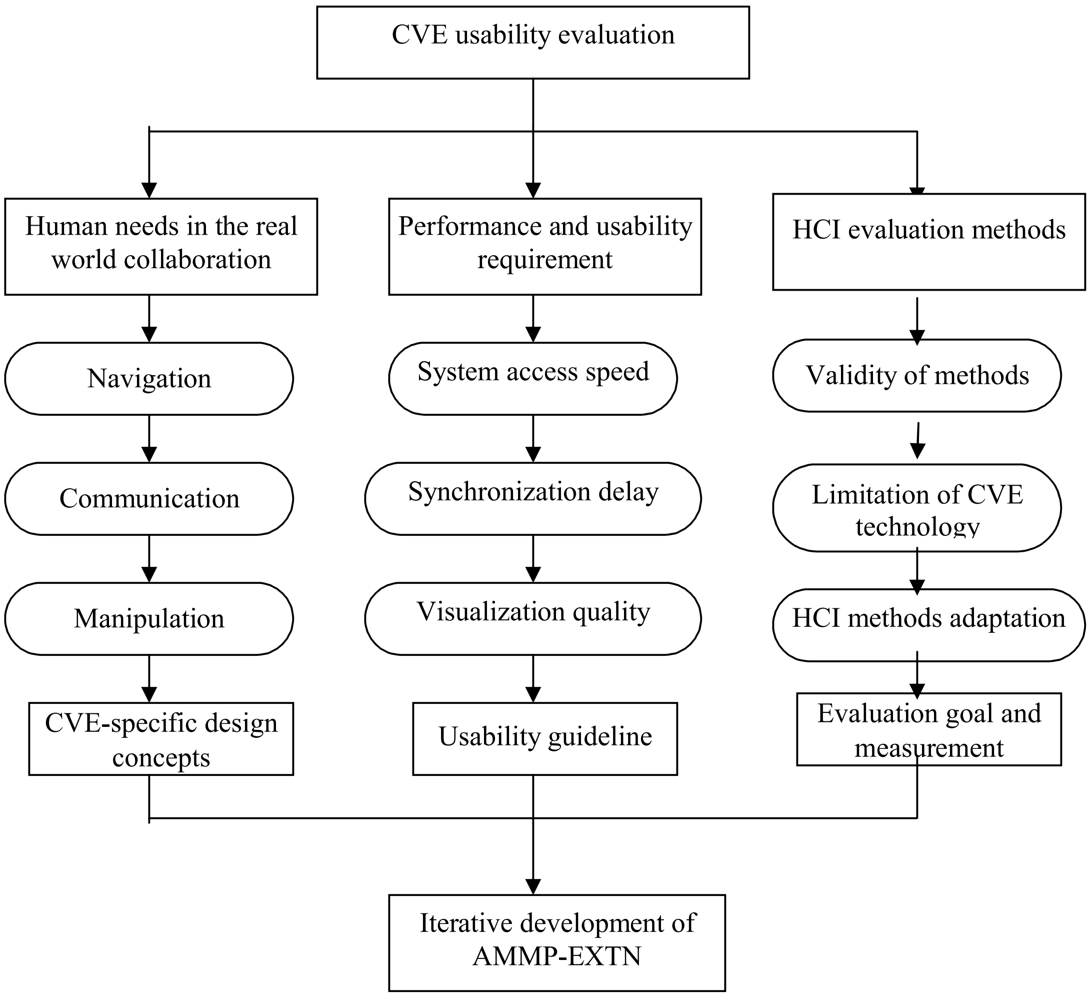


Figure 6-1. Framework of our CVE evaluation and design strategy

Design drawbacks of the CVE system can be categorized into three areas [61]. The first is System problem, including lack of functionality, performance, and service availability. The second area is Interface problem, concerning the content of user interaction, such as dragging the molecule and navigating through the model; the third is Application-specific problem, referring to the meaning of the environment context and objects within the VE.

In the AMMP-EXTN, system performance problems may be apparent when there are either too many sessions supported by the server or too many users present in a session. We need to find the upper bound for the session and user number so that we can set limits on these numbers to guarantee only minor delay of the visualization update on each remote client computer. Interface problem arises largely due to the keyboard or mouse misuse and the absence of user intention awareness in 3D environment. 3D interaction usually requires large user memory to remember the several control modes and keyboard shortcuts for command invocation. Novice users have to struggle and practice before their performance becomes stable. To cope with the difficulty of command invocation in 3D interface, we come up with the 2D control GUI and check if user objective can be met by 2D menu selection, since the matching of interaction task with supporting technique according to the task dimensional nature can improve efficacy of the VE interface [62]. 2D interaction techniques can exist in a 3D immersive VE to satisfy 2D tasks such as selection and text input. Application problem is about how the participants understand the purpose of the applications. Users need to be informed of the type of applications available, the order in which actions should be performed and the meaning of the objects under certain circumstance.

6.1 Cognitive Walkthrough

We employed two well known system evaluation strategies in HCI. They are Cognitive walkthrough and Heuristic evaluation. The cognitive walkthrough is often used for interface evaluation through different stages of the system development cycle. It is conducted by developers and inspectors to assess how easy the interface can be for the first time users. As many users prefer to learn the system through exploratory learning, it is important to know how far they can go and what kind of mistakes they may make. Hence the walkthrough method requires a detailed review of action sequence by which users achieve their task. There are theories [63] of cognition model in HCI and design guidelines [64] about what to check and what questions to ask. We follow this design guideline and add the collaboration goal to the task description step. For each step of action in a collaborative task, we ask the following questions:

1. Will the collaborators know what they should do at this step?

   Will one collaborator know what the other collaborator will do?

   Will the one collaborator know what him/herself is expected to do?
2. Will they be able to find the right tools/commands?
3. Once they find the tool, will they know it is the right one and understand the result?
4. After taking the action, are they able to decide they are doing the right thing?
5. After taking the action, can they understand the feedback from the system of their collaborative actions?

In many cases, the evaluators will easily conclude that the user can select the correct action, and no further analysis is required. For example, during the text chatting within a collaboration group, the message receiver who wants to reply will click "reply" button with little difficulty. Other cases, however, may be less clear to decide. For example, if the collaborator knows that his/her selection of molecules is overridden by users with higher action priority, then he/she should stop trying. The evaluator goes through each action step to explain why or why not certain function or component is good. In addition to Cognitive Walkthrough evaluation, we also plan to take Heuristic evaluation method, which requires users to answer questionnaire about how they feel about the system. This informs us of system deficiency from user's perspective. We will adopt the form of questionnaire given by Sutcliffe and Gault [65] for VR evaluation. It covers many aspects of VR specific issues, such as user presence, natural expression of action, navigation support, and collaboration consistency.

6.2 Automatic User Data Collection

In addition to the HCI inspection method, we also need quantitative data to measure time and accuracy. User performance will be monitored for predefined user tasks. Quantitative data about the number of attempts, frequency of activities, and number of correct result will be recorded and analyzed to identify user behavior patterns. The process of collecting user data for system evaluation includes four steps: data capture, filter and segment, analysis and judgment. Different types of capturing devices, such as eye sensor and voice recorder, can be used. We decide to utilize a log file [14] for automatic data collection since quantitative user history data can be recorded accurately by computer even when multiple users are conducting molecule modeling simultaneously.

User activity and system events will be recorded in the order of their occurrence. Correspondingly, web camera can be used to capture the whole interaction process and video frames may be added to the session log in order to synchronize with the user action record. Usage log file will then go through filters to retain information relevant to the interested UI event. The sequence of actions will be segmented to indicate separate event and correlated to compose high level user task. The system should be able to extract data based on specific requests from the evaluator, e.g. providing records about all molecule dragging events which requires the system ability to decide the start and end of the movement sequence representing that event. This will be studied in our future research work. Finally, in the analysis and judgment step, we will try to summarize the data and predict the cause of usability problems by studying quantitative user data and the interaction patterns extracted from the log file. Moreover, we hope to identify critical incident by behavior counts and statistics, user trace compare and movement sequence characterization. Quantitative measurement should be derived to assess the easiness and accuracy of user interaction, for example, the time delay for typing an input via a dialogue window, the number of mouse clicks for selecting a set of molecule atoms. We need to involve more users in our evaluation and build an estimated user action model in computer to enable automatic user data evaluation.

Chapter 7: Conclusion and Future Work

7.1 Conclusion

As a collaborative Virtual Reality application, the AMMP-VIS molecular modeling system has demonstrated the potential to support mutual, cooperative problem solving and research discovery by providing the immersive shared view and interactive environment to remote users. However, it needs improvement in user coordination support and management. In this paper, we investigate and summarize the high-level design issues that affect the usability of AMMP-VIS, especially in subjective view support, user privacy and action priority control, collaboration synchronization, the transitional interface, collaboration context maintenance, user awareness support and the support for object-focused interaction. These issues not only exist in AMMP-VIS system but also prevail in many other CVR systems. To get an idea of how these issues manifest in current CVR systems and how they can be solved, we conduct a survey of representative CVR application and propose a system taxonomy based on the designers' perspective to the high-level design issues. We divide CVR systems into three categories: navigation, communication and object-manipulation oriented system. In particular, we point out the immediate need in the AMMP-VIS system for solving user action confliction on shared object control.

We have presented our work on the design and implementation of enhanced collaboration control to AMMP-VIS system. The primary contribution of our work, the AMMP-EXTN system, includes the definition of a four-level session access control framework that better addresses the problem of user privacy protection, the design of multiple simultaneous sessions on a single client that offers user more flexible participation choice, the design of user action priority to further solve the manipulation conflict and the proposed integration of text-based communication tool for collaborative session users. In addition, a GUI control interface has been developed to help reduce user memory about command keys and to understand the control options. User can shift among the 3D modeling environments of different sessions and between the 2D GUI and 3D interface easily by using the world shift button.

The details of session design, the collaboration management module and the 2D control GUI are provided. We force individual users to take part in no more than four simultaneous collaborative sessions due to the network capacity concern. Inactive users will be disconnected from the collaboration server to save the management effort. The management Central is separated to three parts, each responsible for the session, user and modeling control respectively. Such implementation gives the benefit of distributing the necessary management functionality on the client side while maintain centralization on the server. In the end, we propose the system evaluation strategy that will examine the specific collaboration task in AMMP-VIS system, the 2D and 3D UI technique and the human behavior character. Our inspection approach includes the adaptation of a HCI method: cognitive walkthrough and an observational approach that use system log file recording and statistical analysis to automate the usability problem finding.

7.2 Insight on the Collaboration Management

The problem of access control on shared object and user privacy control is a delicate issue. In our four-level access control definition, we assign the highest control priority to the session master whose privacy is thus best protected among all collaborators. However, if a new structure is discovered by a collaborator who only has the level of Manipulation Control in the session, he/she can not even access the molecule structure file that records the discovery. Since it is impossible to predict who will be a discoverer who deserves the maximum privacy protection before assigning the control priority, we suggest that user manage to become "master" before making possible discovery. Given the complexity of collaborative activity, it is difficult to guarantee complete user privacy for all participants.

Another major concern is the network bandwidth requirement [19] for providing the real time interactive collaboration in the multiple session views. According to Brodlie et. al [20], visualization pipeline can be distributed partly or fully on the server or client side. By definition, client in a session with Viewing Control access can only accept rendering image from the visualization on the server. The image transmission delay makes it difficult for synchronizing the real time collaboration. In our system, we update the viewer image with a predefined moderate frequency to balance real-time display with smooth image transfer. For collaborators with Manipulation Control, only changes to the molecule structure and modeling parameters are exchanged between the server and client. The temporary molecule file copy on the client for users with access limitation needs to be well protected and deleted at the end of the collaboration. In the future, we plan to use CORBA [21] to manage remote client connection and session control instead of the point-to-point message passing based on TCP/IP protocol that we currently use. The strength of CORBA can be utilized to provide "Object-Oriented" service across different platforms [17].

7.3 Future Work for System Evaluation

User centered evaluation strategy has been proposed in subsection 6.2. Especially, the method of recording objective user data during the system operation has been widely used. We choose the computer aided log file recording method for a complete and convenient documentation of user action traces. The evaluation difficulty lies in the absence of analysis tools for 3D UI interaction and measurement standards. In our formal evaluation plan, we will consider the following issues to enable the automatic user data collection:

1. How to instrument VE system devices and component to record usage trace?
2. How can we integrate monitoring software in our system to record statistical data?
3. How to automatically identify the high level task completion events from the low level device and system events in the log file?
4. How to filter and segment the log file to retain information related to the interested interaction events?

We have made the following observations about the log file evaluation method. User record can be categorized based on the object/device type (e.g. HMD, glove, virtual table-tennis ball), object/device attribute (e.g. HMD direction, glove finger bending degree, virtual ball moving speed), task type (e.g. object rotating, selecting, target catching, virtual walking) and task attribute (e.g. time lap, selection accuracy, foot route). In addition to these low level interaction events, high level abstract events can be defined, such as the selection attempts that exceed the allowed time, the molecule dynamic value out of range caused by user manipulation. In addition, user body position and orientation will also be queried in the interaction analysis. 3D UI analyzer needs to associate the body movements with the possible tracking devices status, e.g. head motion with HMD position or head motion when the eye focus moves; It may be easier to decide the segmentation of action sequence based on the intervals of user behavior, which represent the usually longer thinking time between the completions of two tasks in the VR. To recognize critical user problem, the evaluation system needs to be trained to recognize the behavior pattern that preludes or follows an event.

A comprehensive evaluation is expected after the completion of AMMP-EXTN implementation. We hope the evaluation can help improve the system usability and acceptability. Moreover, we believe that a evaluation method that consists of both subjective questionnaire and objective user data will validate the effectiveness of our collaboration management design and make it a norm for the future development of object manipulation-oriented CVR system.

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