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DESIGNING VIRTUAL ENVIRONMENTS TO SUPPORT COLLABORATIVE WORK IN REAL SPACES

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Typical Collaborative Virtual Environments (CVEs) are a metaphor of real environments, but they are not a copy of them. It is very common in communities that members do not know each other or do not have a real space for meetings. The design of a CVE for people who know each other and interact in a real space is different to the traditional CVE design. It should consider the real location of each resource, appropriate awareness and communication strategies, and human-human and human-resource relations. Our University Department was selected as an example organizational unit for experimentation. We start with the real physical environment and we design a CVE prototype to provide new collaboration features for people working in the unit and for those who will visit it. There are many advantages of the approach. First, people are familiar with the basic physical environment. Second, some activities requiring physical presence can be done with virtual presence, enabling employees to work in convenient ways. Third, new opportunities for collaborative work appear, as it is easy to do them with the proposed CVE. Finally, the approach is extensible, since new features can be added.

Key words: Collaborative Virtual Environments (CVE), Web applications.
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1 Introduction

The development of computational systems supporting human work has increased substantially. More and more, the relationship between communities and technology is a topic of major research interest. The nature of the field requires multidisciplinary research efforts involving researchers from different fields of applied computer science (Computer Supported Cooperative Work, Computer Supported Collaborative Learning, Artificial Intelligence, Information Retrieval, Human Computer Interaction, and Information Systems) and social sciences (Economics, Management Science, Psychology, Political Science, Sociology, Ethnography, Discourse Analysis). Communities are social entities whose actors share common needs, interests, or practices: they constitute the basic units of social experience [23]. People use the word "community" in at least three ways. The word may mean a group of people living in a contiguous geographical area, a group of like-minded people (e.g., the community of librarians, the self-help community, or a "virtual" community) or it may mean a state of group communion, togetherness, and mutual concern [22]. Our proposal is intended to support communities sharing the same work space.

For a number of reasons, researchers are increasingly interested in the topic of communities. First, within a global knowledge-based society, communities play a pivotal role. Problems such as new forms of political participation and civic engagement, the maintenance of cultural identities, or the integration of minorities need to be tackled at the community level. Second, communities also re-shape the processes of learning and sharing knowledge in and among organizations. While earlier approaches focused on storing and retrieving explicit knowledge represented in documents, communities are believed to be important structures to share implicit situated knowledge, as well. Given a new dimension by the use of electronic networks, inter-organizational cooperation is nowadays often discussed in terms of B2B-Marketplaces, Supply Chain Management, Virtual Organizations, or Strategic Alliances [19]. Many failed attempts to implement these approaches can be attributed to inadequate attention to the issues of communities. Finally new types of communities, e.g. on-line communities, might change the relationships between producer and consumer. Information technologies may support or hinder these and other types of communities by enabling communication among (virtual) community members. Research issues include trust-building, maintaining (awareness of) social relations, increase or decrease of social capital, visualization of social relationships, matching (unknown) actors, bridging between physical and electronically-mediated interaction, etc. [20]

The Computer Science Department of our university is an environment where many people work in a shared workspace. Considering the presence of people performing different tasks (professors, secretaries, other clerical employees and research assistants), we believe that the development of a virtual environment where people can collaborate could bring some benefits such as: allow exchange of information among scholars, cooperative writing of academic material, distributed meetings and the like. In order to make use of existing user knowledge, we want the elements of the interface and the operations performed on them to have real world counterparts wherever possible. The background space of a collaborative virtual environment (CVE) may be based on an existing real world domain [11, 12]. Alternatively, it can be based on various spatial metaphors, such as a city or countryside metaphor [1]. The general and basic issue of design is how to structure and design a "good" CVE space, including appropriate metaphors for interaction and visualization. This design can have a significant influence on collaboration. Many experiences have shown that some of the virtual worlds to be visualized should not be created only from models generated in the minds of artists or architects, but rather should also be derived from or augmented by models extracted from real objects [17, 7, 15]. Our goal is to provide a smooth transition from real to virtual work and back by integrating real objects into collaborative virtual environments.

Davenport & Bradley [6] argue that we are bridging the gap between real and virtual worlds as researchers explore new forms of computer-mediated interactions among people, bits, and atoms. Designers are creating tangible user interfaces –digitally augmented spaces, surfaces, objects, and instruments– that make bits physically accessible and managed via graspable objects and ambient media. These interfaces emphasize visually intensive, hands-on foreground interactions and convey information subtly through our peripheral perceptions of the goings-on in the space around us. The room itself, the information that flows through it, the objects it contains, and the people engaged with it become collaborative co-actors.

In this paper, we start with the real physical environment and we design a CVE prototype to provide new collaboration features to the people working in the unit and those who will visit it. The advantages of the approach are many. First, people are familiar with the basic physical environment. Second, some activities requiring physical presence can be done with virtual presence, enabling employees to work in convenient ways. Third, new opportunities for collaborative work appear as it is easy to do them with the proposed CVE. We wish to consider the development of real world based virtual environments which are appropriate for certain kinds of scenarios. In section 2, we present important aspects about how to design virtual environments. The model we propose is included in Section 3. Section 4 contains the model architecture we developed, and finally, section 5 presents some conclusions and further work.

2 Designing virtual environments

There are many definitions of CVE. One interpretation is proposed by West and Hubbold, who describe a CVE as an environment in which people collaborate [26]. They also mention environments which let people cooperate by encouraging interesting and useful behaviors, and collaboratively solve problems with other people. The essential feature of CVEs is that they integrate the participants and the information that they access and manipulate into a single common place [2]. The design, development and use of this kind of systems is a complex process, involving a number of stakeholders. It is also a growing area of research with much potential for interdisciplinary collaboration, particularly between the fields of computer science, psychology, sociology, cultural & media studies, architecture & urban planning, artificial intelligence, human-computer interaction and CSCW [14].

The development of CVEs has been dominated by leisure activities. They are seen as providing on-line social facilities rather than supporting different forms of work [8]. Current understanding about CVEs is poor and there is need for better-designed CVE systems [3].

Creating virtual environments primarily involves designing the environment model and designing user interactions. It is necessary to solve a conundrum: we need to put people and information together in collaboration spaces that inform people about what is happening, but which do not impact on our ability to perform our work. As McGrath and Prinz [16] mention, if we solve this conundrum then surely we can create an on-line space which can be manipulated by a user in a similar way to which she reads and manipulates real spaces.

In order to support collaborative and cooperative activities, it is important that virtual environments offer the means to access appropriate information as well as communication tools [24]. Information sharing is central to collaborative work. As Gibson [9] mentions, collaborative virtual environments are systems, where people can share information through interaction with each other and through individual and collaborative interaction with data representation. In all real world domains, collaborative work involves the interleaving of individual and group efforts, so collaborative work involves considerable complex information exchange [4,18,13].

One important way of social-cognitive support for collaborative activities is to introduce tools for communication, aimed at fostering such productive conversation patterns in the social interaction of collaborating peers [21]. Churchill and Snowdon have proposed a number of key features that CVE software designers should aim to support: Shared context, awareness of others, negotiation and communication and flexible and multiple viewpoints [5].

Designers of collaborative virtual communities now have the opportunity and responsibility to consider the impact of the underlying dynamics of culture and intercultural interactions such as identity, negotiation, conflict, power, equity, and trust on virtual spaces and collaborative communities [27]. Individuals need to negotiate shared understandings of task goals, of task decomposition and sub-task allocation, and of task/sub-task progress. It is important that collaborators know what is currently being done and what has been done in the context of the task goals. Until recently, most CVEs have been used as meeting places where group activities are the central task [10]. Applications for supporting collaborative communities are increasingly available. In addition, the continuing development of global networks means that the opportunities for working, learning, and sharing with various cultures are not only more appealing, but also more feasible. One way we can support collaborative communities is through collaborative virtual environments (CVE).

There is little knowledge about how CVE are being designed, what issues need to be addressed, and little guidance about how visualization of the virtual environments based on standard architecture can be an important factor in the performance of certain kind of communities. Our model includes a design mechanism about mapping a virtual environment to a physical space or structure.

3 The Model

We propose the visualization of a virtual environment based on a real environment. As a case, we study the user interface for the intranet of the Computer Science Department of our university. The Department wants an appropriate Web page for the use of professors, secretaries, other clerical employees and research assistants. Moreover, there are research groups who want to share information, joint work and applications and would like to make all that easily accessible.

In order to make use of existing user knowledge, we want the elements of the interface and the operations performed on them to have real world counterparts wherever possible. However, it is clear that this design goal could not be followed rigidly; otherwise some limitations of the real world would be re-created in the virtual environment, such as the limitation that physical objects can only exist in one place at a time. Based on the DIVA Virtual Office Environment [22], we propose five elements that make up the interaction space: Environment, People, Spaces, Tools, Roles and Privileges.

3.1 Environment

The environment corresponds to the Computer Science Department premises. Figure 1 shows the floor where the main research and administrative activities are performed. It is the third floor of a building.

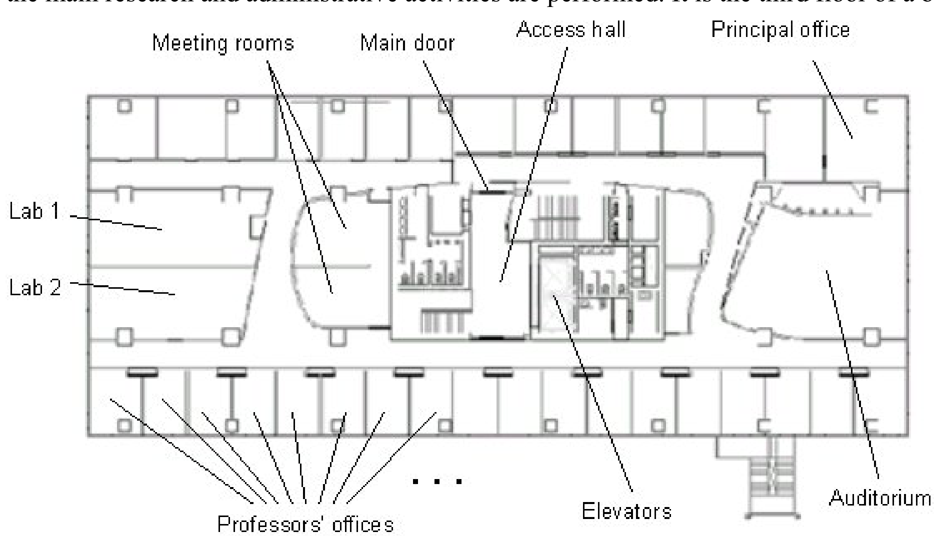


Figure 1. Architectural blueprint of the Computer Science Department physical space

The "environment" for the virtual space is based on the real spaces. Therefore, the blueprint in Figure 1 is the basis for building a virtual space. Naturally, the real space contains parts which are not relevant for virtual work. Stairs or pillars, for instance, are not appropriate for the kind of work the virtual space is intended. Therefore, they should be removed. Furthermore, an abstraction is certainly needed. Figure 2 shows an "improved" version of the real physical environment. Please notice that anyone familiar with the floor will easily find the spaces. Each space in the virtual environment may be defined as a collaboration space. The spaces which are currently defined as virtual collaboration spaces are labeled, such as A (Auditorium), L1 and L2 (laboratories), etc.

The virtual environment on Figure 2 is sensitive to the positioning of the mouse cursor. If the cursor is placed over any of the spaces, some information is shown on the right hand side of the screen. In particular, it shows the contents of the "board" belonging to the space. The board is intended to show information which can be read by any member of the intranet. A typical use of the board is to leave messages about where to locate the person responsible for the space (the *owner* of the space).

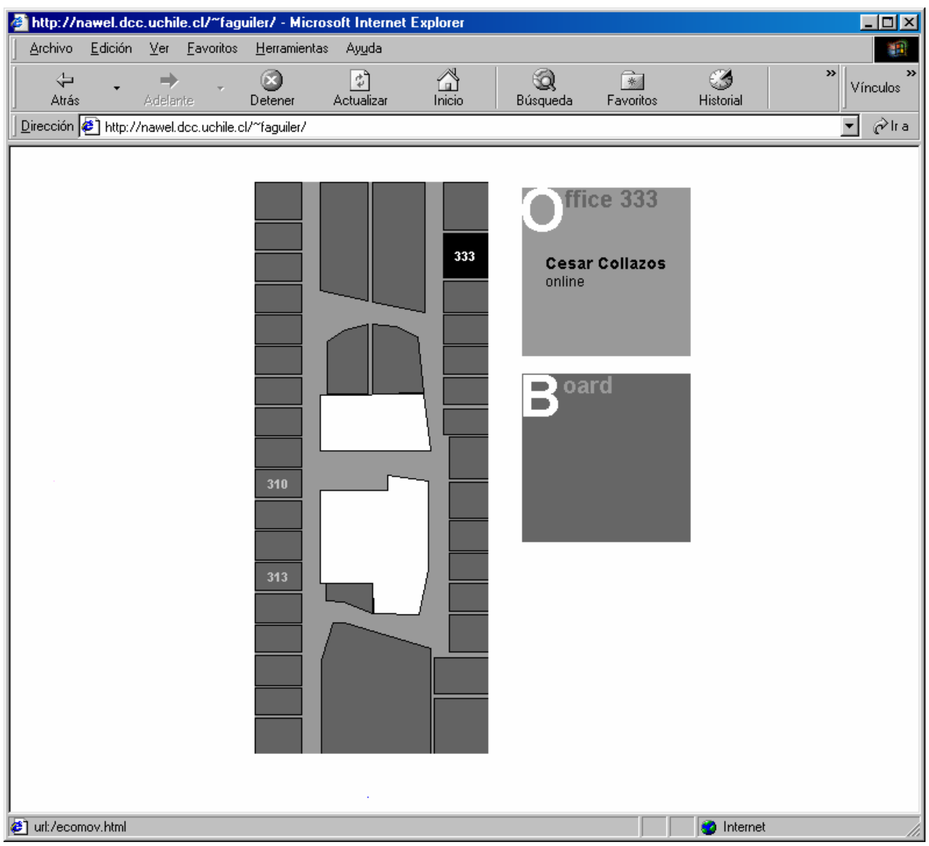


Figure 2. User interface for the CVE of the Computer Science Department

3.2 People

Relevant people for the intranet are certain types of our Department personnel and students. We have classified them into the following categories:

- Professors: academics who perform research, teaching and administration activities within the Department.
- Administrative personnel: people who do administrative and support activities, such as the Financial Officer, secretaries, computer systems engineers.
- Research assistants: graduate students of the department working in research projects.
- Teaching assistants: graduate students supporting courses teaching.
- Students: other graduate and undergraduate students.
- Other academic personnel: visiting scholars, exchange students, project professionals, etc.

People using the CVE need to have identity features. According to this criterion, a person may have a *private* identity*,* a *semi-public* identity or a *public* identity. A private identity means that the person is completely unknown to the system. A public identity, by contrast, corresponds to someone who is known in the system. A semi-public identity is assigned to a person who is partially known by the system.

The identity feature allows different access rights for various kinds of people. In our example, professors and administrative personnel have public identity, a typical student has a semi-public identity and an alien person would have private identity.

3.3 Spaces

The physical environments of the main floor included in our virtual environment are:

- Auditorium: space for talks, seminars, large meetings.
- Office: It is the physical space for individual or small group work.
- Hallways: They are two kinds: Central (access to the elevator), and Interior (access to the offices).
- Meeting Rooms: Spaces specially intended for group work (including the coffee room).
- Laboratories: Spaces for work with non-portable equipment.
- Services: These are rooms for printers, photocopy machines.

These spaces have a privacy feature: they can be classified according to access levels into the next categories:

- Public Spaces: Any person can access them, e.g., the hallways.
- Semi-Public Spaces: They can be accessed only by Department people or by external persons who are invited by Department personnel. For example, the Auditorium is semi-public.

- Semi-Private Spaces: They can only be accessed by specific Department personnel or by their invitation. For example, a Professor's office can only be accessed by him/her or by the people who are invited by him/her, such as a research assistant.
- Private Spaces: They can only be accessed by privileged people. An example is the Financial Officer's office.

The privacy level determines the kind of accessibility a specific space may have. For instance, hallways are always accessible. Other spaces may be semi-accessible: they require a particular action from an authorized person to allow non-authorized people to access them. Such action may remind the opening of a door for a visitor in real space.

It is also possible to classify spaces according to their visibility to people. Three types of external visibility are defined:

- Visible spaces: All activity within these spaces is always visible from outside them. In our example, laboratories, hallways and some administrative offices belong to this category.
- Semi-visible spaces: An explicit action is required to have a view into these spaces. It corresponds to the action of "opening a door" to the physical space and leave it visible from outside. Of course, while trying to open a door, some accessibility checks are performed, similarly to the physical world check of a door: it may be locked and a key is then needed. In our example, professors' offices are typically semi-visible spaces.
- Invisible spaces: These are spaces which can not be seen from outside. In our example, perhaps the Financial Officer's room can only be seen from inside.

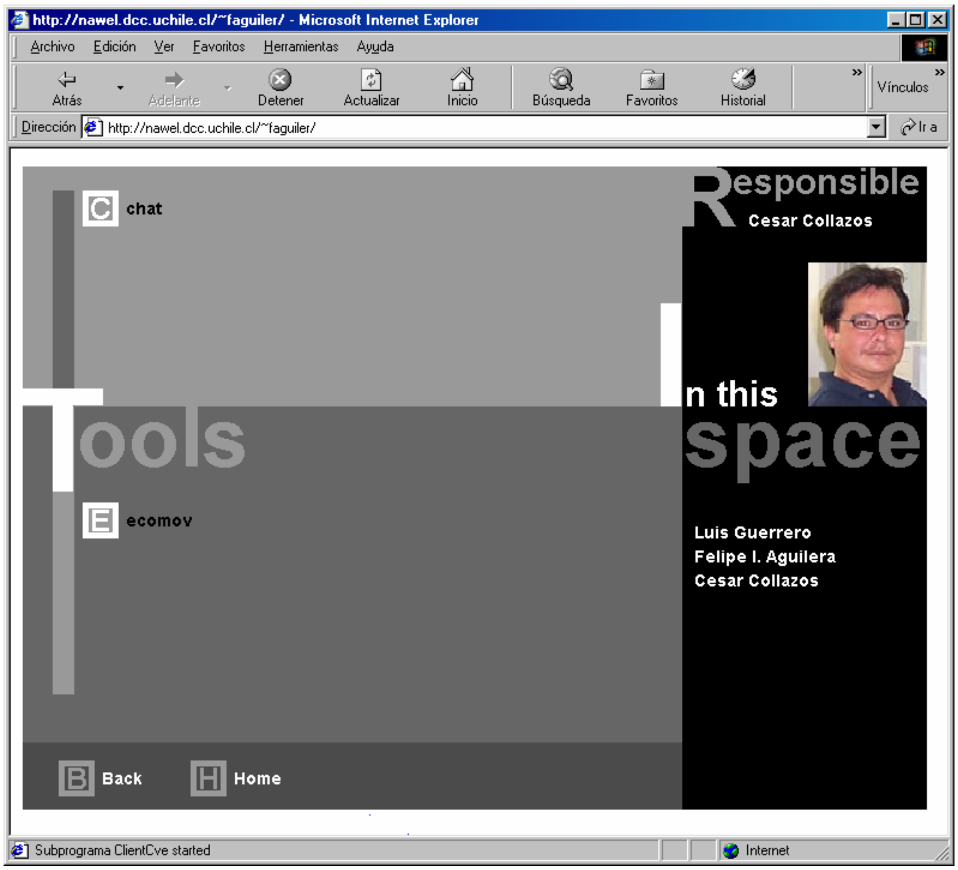
In general, a public or semi-public space will be visible, a semi-private space will be semi-visible and private spaces will be invisible. However, both classifications are independent, e.g., a private space may be defined as visible.

Other classifications are possible. In some cases, it may be necessary to establish the maximum number of people who can be in a certain space, or a concurrency requirement may be met (e.g., students may be at a professor's office only if the professor is present at the same time).

In our example design, if any space has been defined as a collaborative space (it can be identified because it is labeled) then it is possible to "enter" it. Notice that any person who sees collaborative spaces has been previously checked according to her identification (when logging in to the system). A simple click on the mouse allows entering a space over which the cursor stands. A screen similar to the one shown in Figure 3 greets the user.

Within the visual image of a virtual space, there are three sections (graphically, upper, medium and lower part of the screen, as shown in Figure 3). The upper part is open to any person having access to the intranet. It contains basic data about the responsible person for this space. Clicking on the responsible person's picture takes to his personal Web page. It also contains a mail box, to leave messages to the responsible person. Finally, it has a "door" to leave the space.

The medium part of the space window contains a restricted section. It shows the people *currently present* in the space (this presence may be physical or virtual). It also shows a set of tools relevant to the type of cooperation between the responsible person and the one entering the space. For instance, suppose the space is a Professor's office. If the person entering the space is a Teaching Assistant,



perhaps a relevant tool may be a spreadsheet application including course grades. By contrast, if the person entering the space is a Research Assistant, perhaps the relevant tool is a group discussion tool. Finally, the lower part includes two buttons, "back" that permits to go back to the previous level, and "home", that permits to go back to the initial environments.

Figure 3. User interface for a collaborative work space

3.4 Tools

A design assumption is that there are groups within the Department which work collaboratively. Examples of such groups may be a research group, a project team and a teaching unit. Such groups may include people of the various categories as described in 3.2. The collaborative groups share information and applications.

As mentioned above, our design allows access to shared applications and information in the shared spaces to the authorized persons. Notice that the responsible person for each space must specify which tools (including associated information) are to be shared with each person. Of course, such assignments are dynamic: one can think people will begin sharing just one or two tools (e.g. a chat), but will incorporate additional tools as the need arises. Existing tools may certainly be added to the space (see Fig. 4 for an example). These tools will open new windows when invoked, allowing to concurrently work on several applications.

Notice that privacy of tools/information is kept in this approach. People who have no need to access certain information simply do not know such information exists.

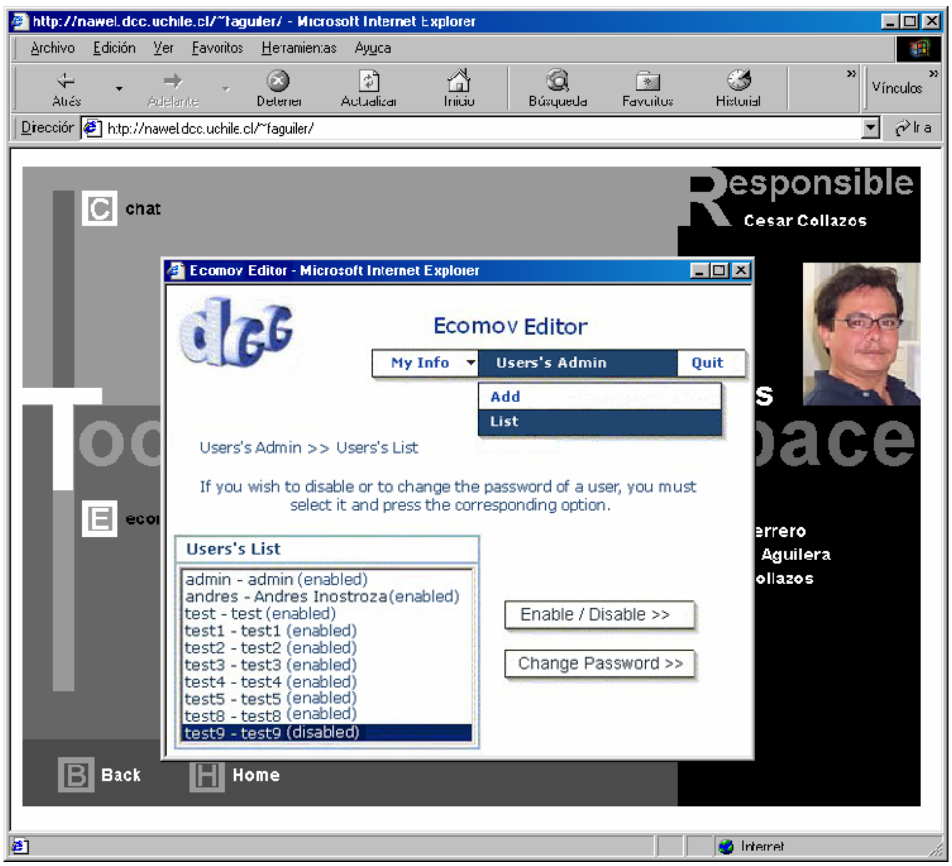


Fig. 4. User interface for a collaborative space

3.5 Roles

The previous presentation introduced some roles in the virtual environment. They are listed below:

- *Responsible person*: This is the person who has one or more specific functions over certain space, e.g., a Teaching Secretary may be in charge of managing the use of the Auditorium.
- *Visitor*: A person who enters a space, e.g., a student may enter a Laboratory.
- *Environment Administrator*: The function of this person is to assign responsible persons to each space.

4 Model architecture

The previous case illustrates a situation in which a basic architectural blueprint is the starting point for a user interface allowing simple access to a complex computer-based system of collaboration features and privacy restrictions. The familiarity of the users with the real architecture eases the access to virtual services which enlarge the opportunities for collaboration: people do not need to physically go to a certain space to be able to interact and work together with some other people.

The physical to virtual transition can be made using all the metaphors that may be useful. For example, we have mentioned that in the case study, the labeled spaces are meant for places that have been designated as "collaboration spaces" by the corresponding responsible persons. This was inspired by the following physical analogy. Our offices have a high ceiling and the walls facing the hallway have transparent glass in the upper part; if the lights are on, this is clearly visible from the corridor. In other words, there is a simple awareness mechanism to tell when people are physically present in their offices and (hopefully) willing to collaborate.

As we have mentioned, the physical to virtual transition is abstracted. It may be enlarged also. For example, in the user interface of the CVE for the Computer Science Department we could invent a "recreation room", where users could play multi-user games. Of course, the enlargements should be modest; otherwise the physical to virtual resemblance may be lost.

We can think that the relationship can go in the other direction as well. When preparing the user interface for a CVE, it may become clear that certain physical spaces should move to other locations because they are functionally disconnected. In a certain way, this is similar to the re-engineering that results from trying to automate processes in an organization: when designing the workflow, it becomes obvious that certain processes should be modified before automating them.

The case study is useful to illustrate a type of environments we may call Collaborative Virtual/Real Environments (CVRE). We may characterize such environments as a pair of a real environment (such as the physical floor of our Department) and a virtual environment based on the real one (such as the user interface to the Departmental intranet). Each environment benefits from the existence of the other.

The virtual part of a CVRE may be modeled as follows, assuming the characteristics we have described for our Department case. The environment has a set of tools (and their relevant data files) associated to it. The environment provides a map of the site and organizes people and information by providing data and user awareness. The spaces provide places for people interaction and where tools can be used. Figure 5 shows a tree structure in which the nodes are the spaces. The nodes and their links define a navigation model. For instance, in Figure 5, from the environment it is possible to go to the Auditorium (node A); from there, it is possible to go to any of the conference rooms inside it (nodes C1, C2, C3). Note that people who have no rights to enter to the Auditorium will never know there are three conference rooms inside it. This is a parallel to the physical (real) situation.

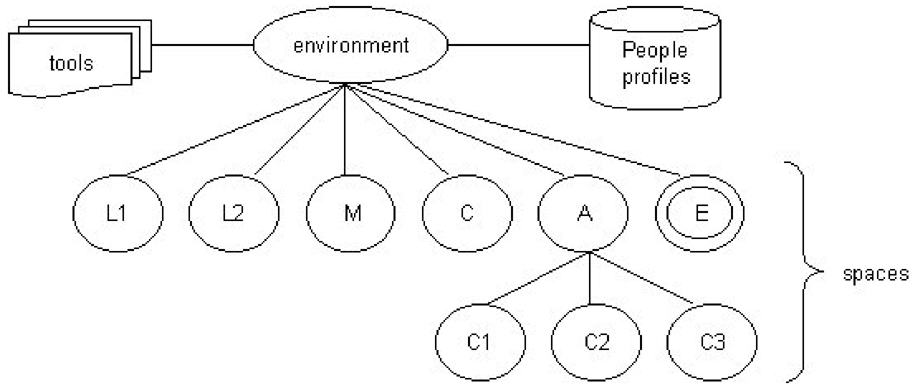


Figure 5. CVRE architecture (virtual part).

Notice in Figure 5 the especially marked node E. It corresponds to the Entrance to the environment. Its user interface is similar to the other spaces. It is the only completely public place. Any person can access it and may use the designated available tools. Therefore, this space is useful to offer public information. Behind the "door" of this place is the environment. Again, this is similar to the real situation, in which, people crossing the entrance door are already in a semi-public space. In the virtual part of the CVRE, a person is required to submit a login ID and password.

The door from the entrance to the environment is the only place where people are requested to identify themselves. The system provides this feature, since every time a person navigates in the tree structure; the current node sends a message to the next space with the person's data. Each node has its own list of authorized users to enter it, as well as the available applications for each user. Therefore, when a person moves from a space to another, the new space is configured according to the person's roles and privileges. Again, people are not shown things they should not see. Each space has a responsible person, who must configure the list of authorized persons to enter the space and the tools that will be offered to them.

5. Conclusions and further work

There are many reasons why researchers are increasingly interested in the study of communities. The model we have proposed could be useful for some communities for which there is a strong relationship between real and virtual environments. In this case, the existence of a CVRE can reinforce the physical/virtual world association, with benefits for both. In the case of our Computer Science Department, for instance, this model could help to support collaborative and cooperative activities, because the environments offer the means to access appropriate information as well as awareness tools. People can physically visit a colleague because the virtual system indicates he is physically present. Or, the hints of physical presence can motivate a person to work together with the colleague in the virtual world (distributed work using the intranet).

The model we have proposed includes a set of elements (Environment, People, Spaces, Tools, Roles and Privileges) that could be easily adapted for the design of a CVRE when the users are people who have knowledge of the real environment. Setting up the virtual part of a CVRE is an opportunity to re-think the physical part of the CVRE: the physical spaces could be re-assigned to reflect the best use of teams who may want to be closely located. Finally, the virtual part of the CVRE is very flexible and dynamic: people will always be changing authorizations and available tools. Our CVE is in a prototypical stage. We expect to include several individual and collaborative tools into the system. This should make the system increasingly useful to the community members. In the short future we plan to include a shared agenda, a group to-do list (which may be associated to a workflow engine), a pre-meeting discussions tool and a shared spreadsheet.

The design of the proposed environment could bring some elements that permit support collaborative activities at the Department, and could be adapted and reused in order to model other CVEs with similar characteristics. Thus, a relatively similar CVE to the one used in our Department does not need to be created from scratch.

People being introduced to a CVE should find natural to use it if they are accustomed to a real environment in which the CVE is based. This because the conceptual layout is the same and the access protocols should be similar. This was our initial assumption and the main lesson learned was this was tentatively confirmed. Our design is an in-progress research that could be of interest for many organizations, not just for academic ones.

Acknowledgements

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References

1. Benyon, D., & HööK, K.,Navigation in information spaces: supporting the individual. In: Human-Computer Interaction: Proceedings of Interact'97. S. Howard, J. Hammond and G. Lindagaard (eds). London: Chapman & Hall, 1997.
2. Benford, S., & Brown, C., Reynard, Greenhalgh, C. Shared spaces: Transportation artificially and spatially. Proceedings of the 1996 ACM Conference on Computer Supported Work, pp. 77-86, Boston, MA, 1996.
3. Bolas, M., Designing virtual environments. In: The Virtual Reality Casebook, C.G. Loeffler and T. Anderson (eds.), New York: Van Nostrand Reinhold, 1994.
4. Bowers, J., & Martin, D., Informing collaborative information visualization through an ethnography of ambulance control. Proceedings of ECSCW'99, Copenhagen, pp.311-330, 1999.
5. Churchill, E., & Snowdon, D.,Collaborative virtual environments: an introductory review of issues and systems. Virtual Reality: Research, Development and Applications, 3, pp.3-15, 1998.
6. Davenport, G, & Bradley, B., The care and feeding of users. In: Visions and Views, IEEE Multimedia, Jan-March, pp. 8-11, 1997.
7. Debevec, P., Taylor, C., & Malik, J., Modeling and rendering architecture from photographs: a hybrid geometry -and image- based approach. Proceedings of Siggraph'96, ACM Press, New York, pp.11-20, 1996.
8. Frecon, E., & Nou A., Building distributed virtual environments to support collaborative work. ACM Symposium on Virtual Reality Software and Technology, VRST'98, pp.105-113, Taipei,Taiwan, Nov. 1998.
9. Gibson, W., Neuromancer. New York: Grafton, 1989.
10. Greenhalgh, C.,Analyzing movements and world transitions in virtual reality tele-conferencing. Proceedings of Fifth European Conference on Computer Supported Cooperative Work, ECSCW'97. Dordrecht: Kluwer Academic, 1997.
11. Guerrero, L, Collazos, C., Pino, J.,Aguilera, F. & Ochoa, S., Collaborative Virtual Environments Based on Real Work Spaces, Proceedings of HCI International, Lawrence Erlbaum Associates, Inc, Crete, Grecia, June, 2003, Vol. 4, pp. 1113-1117. C. Stephanidis (ed.).

12. Guerrero, L. A., Collazos, C., Pino, J., Ochoa, S., & Aguilera, F., Designing Collaborative Virtual Environments Based on Real Spaces to Promote Community Interaction. Proceedings of the First Latin American World Wide Web Conference (LA-WEB 2003), IEEE Computer Society Press, November 2003, Santiago, Chile, pp. 58-65
13. Heath, C.,& Luff, P., Collaborative activity and technological design: task coordination in London Underground control rooms. L. Bannon, M. Robinson and K. Schmidt (eds.), Proceedings of ECSCW'91, Dordrecht: Kluwer Academics, pp.65-80, 1991.
14. Jackson, R., & Fagan, E., Collaboration and leanring within inmersive virtual reality. Proceedings of Collaborative Virtual environments. San Franciso, USA, pp.83-92, 2000.
15. Kande, T., Rander, P., Vedula, S., & Saito, H.,Virtualized reality digitizing a 3D-time-varying event as is an in real time. In: Mixed reality, merging real and virtual worlds, Yuichi Ohta and Hideyuki Tamura (eds), Springer-Verlag, pp.41-57, 1999.
16. McGrath A., & Prinz, W., All that is solid melts into software. In: Collaborative Virtual Environments: Digital Spaces and Places for CSCW: An introduction. E. Churchill, D. Snowdon and A. Munro (eds), pp.99-114, 2001.
17. McMillan, L., Bishop, & G., Plenoptic modeling: an image-based rendering system. Proceedings of Siggraph'95, ACM Press, New York, pp-39-46, 1995.
18. Moran, T,& Anderson, R., The workaday world as a paradigm for CSCW design. Proceedings of CSCW'90, New York: ACM Press, 1990.
19. Mynatt, E., & Adler, A., Ito, M., & O'Day, V., Network Communities: Something Old, Something New, Something Borrowed, Something Blue. Computer Supported Cooperative Work, 7(1). Kluwer Academic Publishers, Dordrecht, 1998.
20. Mynatt, E., Adler, A., Ito, M., & O'Day, V., Design for network communities. In Proc. Of the ACM Conf on Human Factors in Computing Systems (CHI97), pp. 210-217, Atlanta, USA, 1997
21. Pauli, C., & Reusser, K., Supporting collaborative problem solving: supporting collaboration and supporting problem solving. Proceedings of Swiss Workshop on Collaborative and Distributed systems, 1997.
22. Schuler, D., New Community Networks. Addison-Wesley Publishing Company Inc, 1996.
23. Schwartz, E.., Building community. Philadelphia, PA: The Institute for the Study of Civic Values, 1991.
24. Snowdon, D., Churchill, E., & Munro, A., In Collaborative Virtual Environments: Digital places and spaces for interaction E. Churchill, D. Snowdon and A. Munro (eds), pp. 3-19, 2001.
25. Sohlenkamp, M. , virtual office environment supporting shared applications. Proceedings of 3rd. International Montpellier Conference Interface to Real and Virtual Worlds, EC2, Paris, France, pp.163-173, 1994.
26. West, A., & Hubbold, R., System challenges for collaborative virtual environments. In Collaborative Virtual Environments: Digital places and spaces for interaction. E. Churchil, D. Snowdon and A. Munro (eds), pp. 43-54, 2001.
27. http://www.sandia.gov/media/NewsRel/NR2000/virtual.htm

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