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Navigating 3D Virtual Environments by Following Embodied Agents: a Proposal and its Informal Evaluation on a Virtual Museum Application

Luca Chittaro♣, Lucio Ieronutti, Roberto Ranon

HCI Lab
University of Udine, Italy

ABSTRACT

Many 3D virtual environments (e.g., 3D Web sites) do not offer sufficient assistance to (especially novice) users in navigating the virtual environment, find objects/places of interests, and learn how to interact with them. This paper proposes the adoption of guided tours of virtual environments as an effective user aid and describes a novel tool that provides automatic code generation for adding such guided tours to 3D virtual environments developed using the VRML language. In the second part of the paper, we informally evaluate the proposed approach on a real-world application concerning a 3D computer science museum (a complement to a real-world exhibition focusing on the history of computer technology).

Keywords: *3D Virtual Environments, Navigation Aids, Virtual Museums, Embodied Agents.*

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1. Introduction

A well-known factor limiting the diffusion and popularity of 3D interfaces (e.g., 3D Web sites on the Internet) is their scarce usability (especially from the point of view of novice users). While developers of traditional 2D interfaces (e.g., traditional 2D Web sites) are aware that usability is one of the key issues for the success of their applications and rely on guidelines and tools that support them in this direction, 3D content creators have generally neither well-established 3D-specific guidelines nor specific tools available to help them.

In our research, we are concentrating on finding ways to increase the usability of 3D interfaces. In this paper, we consider a specific usability problem that affects many 3D

♣ Corresponding Author:
Luca Chittaro
Dept. Of Math and Computer Science
Via delle Scienze, 206
33100 Udine, Italy
email: chittaro@dimi.uniud.it

virtual environments, i.e. insufficient user assistance during exploration, and propose an approach aimed at helping the 3D content creator to face the problem with little effort.

The considered solution is based on exploiting an embodied agent, making it able to lead the user on a guided tour of the 3D virtual environment. This solution is at the same time a navigation aid (since it helps users in finding places of interest) and an information aid (since the agent is also able to provide information about the encountered places and objects). The introduction of an embodied agent can also have the additional advantage of making the 3D virtual environment more lively and attractive for the user.

Unfortunately, developing guided tours led by embodied agents is not an easy task for the 3D content creator, since it currently has to be done partly by hand (e.g., coding a suitable path for the virtual agent avoiding obstacles). Moreover, the code written for one 3D virtual environment can be very limitedly reused for other ones. The aim of this paper is to aid the 3D content creator by proposing an automatic approach to solve the considered problem. The current implementation of the approach is targeted at 3D virtual environments developed using the VRML language (VRML, 1997), a ISO standard language to develop 3D content for the Internet. The detailed description on how the approach has been implemented can be found in (Chittaro et al., 2003), while this paper focuses on the conceptual features of the approach and its informal evaluation.

The informal evaluation of the approach has been carried out on an application concerning a 3D virtual museum we recently developed as a complement to a real-world exhibition focusing on the history of computer technology. The 3D virtual museum application allows one to visit a virtual reconstruction of a computing centre of the '70s that shows the corresponding equipment of the real-world exhibition in its original environment of operation and provides information about its features and functioning. To make the visiting experience more engaging and effective, we exploited the tool proposed in this paper to build a human-like agent that acts as a virtual guide, being able to lead the user on a guided tour explaining some/all the objects in the museum in a logical order.

This paper is structured as follows. First, in Section 2, we advocate the exploitation of virtual tours with embodied agents as guides to effectively aid users in 3D virtual environments, and compare it with other proposed navigation aids (e.g. maps, viewpoint tours). In Section 3, we illustrate our approach to build guided tours with embodied agents, and show how a 3D content creator can use it as a stand-alone tool for automatic code generation. Section 4 describes the 3D Computer Science museum and illustrates the capabilities of its virtual guide. In Section 5, we present the results of an informal evaluation of the museum virtual guide on users, and draw some interesting lessons on the exploitation of embodied agents in 3D museums and exhibitions.

2. Motivations

Many 3D virtual environments, whether representing existing places (e.g., virtual cities) or imaginary ones, typically leave the user alone and partially or totally unassisted in navigating the environment, discover points of interest, and interact with objects. Although in games this can be a desirable situation, it is definitely not in applications devoted to other purposes (such as virtual tourism, training, museums, e-commerce,...). Leaving the user unassisted can lead to a number of usability problems, ranging from navigation issues (e.g., wayfinding) to difficulties in figuring out which operations can be performed on the objects in the virtual environment. In the following, we analyze these issues in detail.

2.1. Navigation Issues

The lack of proper navigation support causes the user to suffer from well-known navigation problems (e.g., disorientation). As a result, visitors of a virtual environment can: (i) become rapidly frustrated and abandon the visit; (ii) miss interesting parts of the environment (especially in large ones), and (iii) complete the visit with the feeling of not having adequately explored the environment.

This is particularly true for novice users of a virtual environment, who should be helped as much as possible during navigation by offering them proper navigation aids. To this purpose, a first category of solutions can be derived from the design of real-world environments. For example, in the design of buildings, architects aim at reducing wayfinding problems for the people exploring the building by increasing visual access (i.e. the number of parts of the environment which can be seen by a person from her position in space) or including navigational cues (e.g., room numbers, names of buildings, landmarks). Landmarks are distinctive environmental features (e.g., a statue, a river, a town square, …) functioning as reference points (Vinson, 1999). However, this kind of solutions can be limitedly applied to 3D virtual environments that are virtual reconstructions of existing places, where the architecture of the environment cannot be modified.

A second category of solutions (that can be possibly combined with the above mentioned ones) aims at providing the user with electronic navigation aids to augment her capabilities to explore and learn. A well known example in this category are the various types of electronic maps of the environment that help users orient themselves (see, e.g., (Darken and Sibert, 1996)). However, electronic maps adopt a third-person perspective, which can require a considerable cognitive mapping effort to be correctly interpreted (e.g., consider the typical real-world situation where someone is trying to find her way in a city by using a map and has to translate the exocentric view of the map into her egocentric view). This claim is supported by psychological studies, e.g. Thorndyke and Hayes-Roth (1982) compared spatial judgment abilities of subjects who learned an environment from personal exploration or from a map, highlighting the difficulty of changing perspective (e.g., subjects who acquired knowledge from the exocentric map perspective were most error prone in tasks that required to translate their knowledge into a response within the environment). Other classes of proposed navigation aids include:

- 3D maps, such as Worlds in Miniature (WIM) (Stoakley et al., 1995). A WIM is a three-dimensional small scale version of the 3D virtual environment, standing in front of the user, as if it were in his virtual hand. The user can directly manipulate both the WIM and the environment (changing something in one of the two directly affects the other and vice versa);
- constrained navigation approaches, that restrict user's freedom of movement. Placing constraints on user's motion allows for a simplification of the effort needed to navigate the 3D virtual environment. For example, Galyean (1995) has proposed a method that guides the user's continuous and direct input within both space and time using a river analogy, while Hanson and Wernert (1999) present an approach where a user's navigation can be constrained to the movements of another user or of an automated guide.

In the following, we focus on a solution belonging to the navigation aids category.

2.2. Getting Information about the Virtual Environment

Another difficulty that can be experienced by the visitor of a virtual environment is to determine what she can do with objects and how to get information about them. Instructions to the user are typically provided by introductory pages, which describe the contents of the virtual environment, and how to interact with objects. Many users typically skip these introductory pages and later fail to explore parts of the virtual environment because they are not aware of all the possible actions.

Providing information about objects can be crucial, for example, in virtual museums, virtual training and e-commerce sites, where getting additional information is a fundamental part of the user experience. For example, in the case of 3D Web sites, some researchers face this problem by providing the information during the visit in a separate HTML frame. However, this solution has the disadvantage of decreasing user immersion.

2.3. A Possible Solution: Using Embodied Agents as Guides

One of the solutions that can take into account all the previous concerns is to offer tours of the 3D virtual environment. Moreover, from the 3D content creator perspective, the possibility of offering tours allows one to naturally suggest preferable ways to visit the virtual environment. For example, this can be important in virtual exhibitions, museums, and cities.

Simple forms of (unguided) tours are already offered by some 3D virtual environments by providing a set of viewpoints through which the user has to cycle to visit the environment in a certain order. However, while viewpoints can be useful for quickly navigating the environment, they are not easy to use for learning navigational knowledge, such as paths, relating the different parts of the environment (if teleporting is used, they also break the continuity of the experience, further contributing to user disorientation).

The approach we adopt in this paper is to provide the user with guided tours based on an embodied (more specifically, a humanoid) agent that acts as a *virtual guide*, i.e. it is able both to lead the user to the required places and to provide information through a semi-transparent *On Screen Display* (*OSD*) available inside the 3D virtual environment. In the following, we discuss in detail how this approach addresses the previously illustrated concerns, and the benefits of using embodied agents as virtual guides.

First, virtual guides are navigation aids, leading users around and preventing them from being lost: the user has simply to follow the guide to visit the virtual environment. As pointed out by Rickel and Lewis Johnson (2000), showing the user where relevant objects are and how to get to them is likely to be more effective than trying to tell users where objects are located. For example, informal experiments with users in a virtual city showed that the environment was explored to a greater level and by an higher number of users as a result of tour guides explaining how to get the most out of the system (Ennis and Mayer, 2001). Moreover, the expert user has still the possibility to ignore the guide and follow her own tour, but it is very likely that novice users will instead appreciate and use the aid. While a virtual guide does not directly help the user properly controlling its movements to avoid some typical 3D navigation problems (e.g., bumping into obstacles), a properly chosen tour can lower the probability that the user finds himself in positions where it can be difficult to find a way (e.g. corners).

Second, virtual guides can be also employed as a natural way to provide users with additional information (e.g. usage of a particular object) during the visit, instead of providing this information into separate pages. For example, a virtual museum guide could give an introduction at the beginning of the visit and later present specific items on display, possibly explaining how to interact with them. With respect to other forms of user guidance, an embodied agent can draw user's attention with the most common and natural methods, such as gaze and pointing gestures (Rickel and Lewis Johnson, 2000). Moreover, the guide can also use its body orientation as a cue to the suggested attentional focus (Rickel and Lewis Johnson, 2000).

Third, introducing an embodied agent in the virtual environment can contribute to alleviate an additional problem, i.e. most virtual environments where the user is left completely alone look like dead places (like just after the builders have left the building), that are less attractive to the user. Embodied agents can make instead the virtual place more lively, attractive, and less intimidating. Results of empirical studies show that embodied agents may have a strong motivational impact: users tend to experience presentations given by embodied agents as lively and engaging (Lester et al. 1997; van Mulken et al. 1998).

Finally, we concentrated our attention on guides that travel around the virtual environment by simply walking (i.e., they do not fly, crawl, ...). Indeed, it would be very difficult for the user to follow paths that require movements other than walking, e.g., free flying in a 3D space is known to be very difficult for novice users.

3. Deriving Virtual Tours for 3D Virtual Environments with Virtual Guides

Achieving the previously illustrated goals requires to deal with a number of different problems, ranging from the derivation of suitable paths for the virtual guide, to choosing how to present objects/places of interest to the user.

The tool we present, called *VRML Tour Creator*, aims at providing fully automatic code generation, allowing the content creator to concentrate only on high-level aspects (e.g., which objects/places of the virtual environment need to be presented, what could be the text for their presentation,...). More specifically, the inputs of the VRML Tour Creator are the VRML file describing the virtual environment in which the guided tour needs to be inserted, the 3D model of the embodied agent which will act as a virtual guide, and the tour data, i.e. the descriptions and the locations of the objects/places to be presented. The tool then outputs a new version of the VRML virtual environment that includes the generated code for the guided tour.

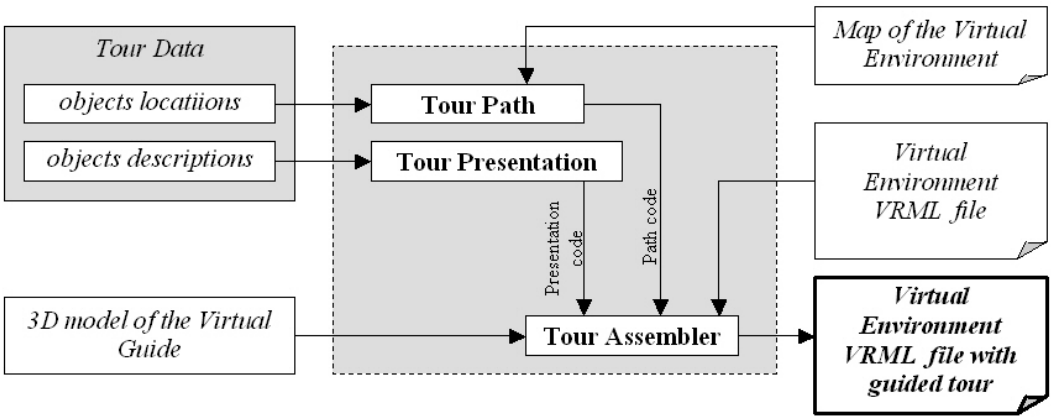

Fig. 1: Architecture of the VRML Tour Creator

The general architecture of the VRML Tour Creator (which has been implemented in Java) is depicted in Figure 1. It is mainly composed by three modules: a *Tour Path* module, a *Tour Presentation* module and a *Tour Assembler* module.

The function of the Tour Path module is to derive an appropriate sequence of positions that will be used to move the guide from each object/place to the subsequent one in the desired tour.

The approach we follow to deal with the problem of deriving a suitable set of positions for the guided tour is based on using a path planning algorithm that takes as input a map of the VRML virtual environment (which is automatically generated using the approach described in (Ieronutti et al., 2004)). In particular, we adopted a modified version of a well-known grid-based path planning approach (Latombe, 1991) from robotics, which provides a good compromise between simplicity and generality, and guarantees that the virtual guide, following the calculated path, will not collide with other objects in the virtual environment (more details can be found in (Chittaro et al., 2003)).

The Tour Presentation module derives the VRML code for the presentation of each object/place in the tour. Each presentation is displayed in the semi-transparent OSD that appears at presentation time and/or is narrated by the embodied agent using a text-to-speech engine.

The Tour Assembler module uses the outputs derived by the two previously described modules together with other inputs to assemble the code for the guided tour and include it in the virtual environment.

4. Case Study: a 3D Virtual Computer Science Museum

3D interfaces are increasingly used in the museum domain, both as a complement and extension of existing real-world museums (e.g., Virtual Reality theatre rooms, such as the CAVE system (Cruz-Neira et al., 1993)) and as a means to build entirely virtual museums (e.g., to be visited from the Web or to be taken on tour). For example, Barbieri and Paolini (2001) developed a multi-user virtual environment that shows Leonardo's works in an application for the Italian National Science Museum, while (Chiu et al., 2000) developed a 3D virtual museum, called Virtual Architecture Museum, focused on modernist asian architecture.

Fig. 2: Some units of a real Univac Sperry 90/30 computer.

Fig. 3. Top view of the virtual data processing centre.

With respect to a 2D solution (e.g., a collection of HTML pages), a 3D virtual museum allows one not only to display the museum items, but also to convey their "cultural setting" (since it constitutes an important part of the display) by inserting them in a proper environment (Hendricks et al., 2003).

Recently, we developed a 3D Computer Science museum based on a VRML virtual environment representing a data processing center of the 70's, reproducing hardware from the Univac/Sperry 90/30 line (shown in Figure 2). In the virtual environment, visitors can either freely navigate or follow guided tours, observe the different devices and people at work, and learn the features and functioning of devices. The main pedagogical goals for our virtual museum are concerned with pointing out the several differences existing between data processing centers in the '70s and current computer machines, e.g. the mainframe – terminals architecture and the interaction based on text video terminals or (more often) punch cards. The virtual data processing centre is divided into two main rooms (as shown in Figure 3):

- a computer room, containing the main system, in which data processing is performed under the control of a technical staff (i.e., experts in computer science or in electronic engineering);

- a terminal room, containing punch card units and video terminals, in which activities that are mainly preparatory to real data processing are carried out by other people, usually less expert in computer science, but more competent in the specific problems to solve.

Museum visitors can click on any device, and see and/or hear a description of its features and functioning.

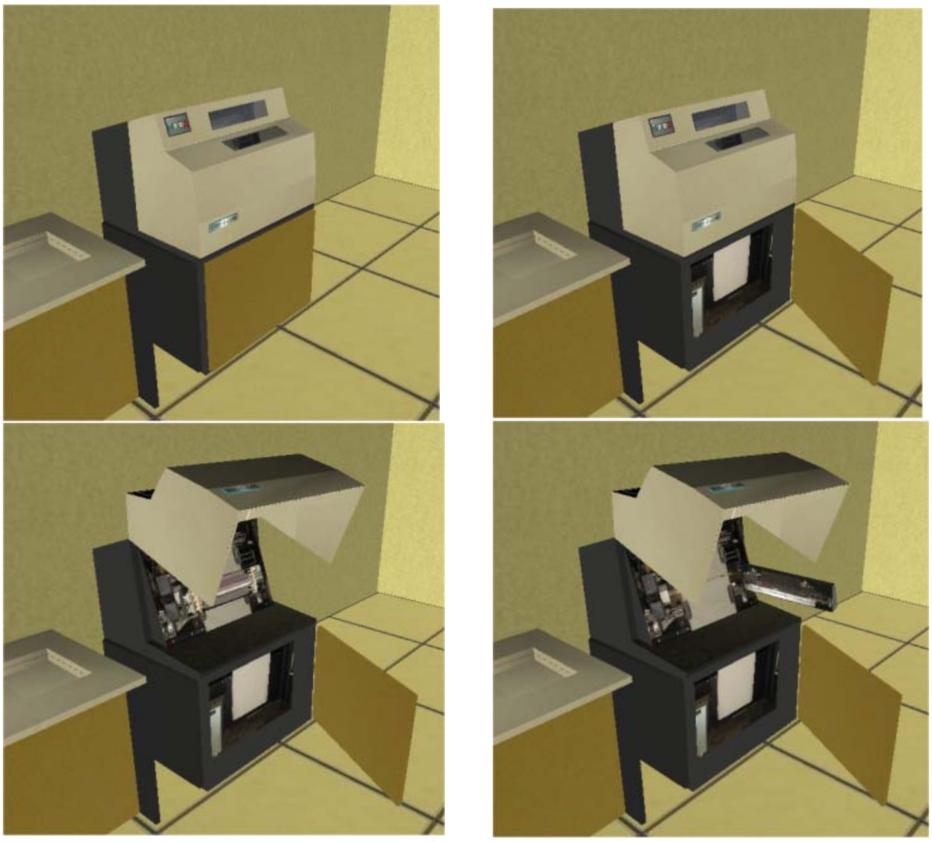

Fig. 4: An interactive component: the main printer.

To improve learning effectiveness, most devices are interactive and some are animated. For example, the user can open cabinet units to examine their internal details and working (as with the main printer illustrated in Figure 4).

To increase the realism of the user experience, we added the necessary furniture and included typical professional figures at work. Moreover, the audio channel is used to add typical noise and sounds of objects and human actions (for instance, printers, terminal operator typing, etc). Noise and sounds augment the immersiveness of the experience of the visitor and also help focusing the attention during the visit.

4.1. A Guided Tour of the Computer Science Museum

Visitors of the museum can either freely navigate or follow a guided tour lead by the embodied agent (shown in Figure 5). As the user enters the 3D Computer Science Museum, the embodied agent performs an introduction to the subject, and invites the user to follow it on a tour, which encompasses some (or all) of the museum items. Each tour is composed by a sequence of presentations (each one referring to one museum item). For each presentation, the guide: (i) walks from its actual position towards the item that has to be presented (showing the user the way to reach it); (ii) presents the item (see Figure 5); (iii) waits until the user clicks on the guide itself, and then proceeds to the next item in the tour. While the presentation text is displayed and/or spoken, the guide mimics a talking person (see Figure 6). Additionally, when presenting an object, the guide periodically switches its attention between the user and the object to both give the user the feeling that the guide is addressing her, and to ensure that the attention towards the required object is clearly directed. Visitors are not forced to follow the guide; they can autonomously visit the environment and possibly come back later and resume the guided tour by clicking again on the guide.

5. Informal Evaluation on Users

The aim of the evaluation we carried out on the 3D Computer Science Museum was twofold: first, we wanted to assess whether the virtual guide was appreciated (and exploited) by users; second, we wanted to identify strengths and weaknesses of the guided tour approach, and get feedback about how to improve the system.

Subjects

A total of 20 subjects were involved in the evaluation. The subject population was representative of the diversity of visitors of the real exhibition. Age ranged from 20 to 55, averaging at 30. The population was almost equally split between males (11) and females (9). Occupation of the subjects ranged from clerk to high school teacher, engineer, and student. With respect to familiarity with 3D environments, 30% of the population was familiar with 3D environments (mostly videogames), 40% of the population had visited only one or two 3D environments, and the remaining 30% had never visited a 3D environment.

Fig. 5. The virtual guide presenting a printer.

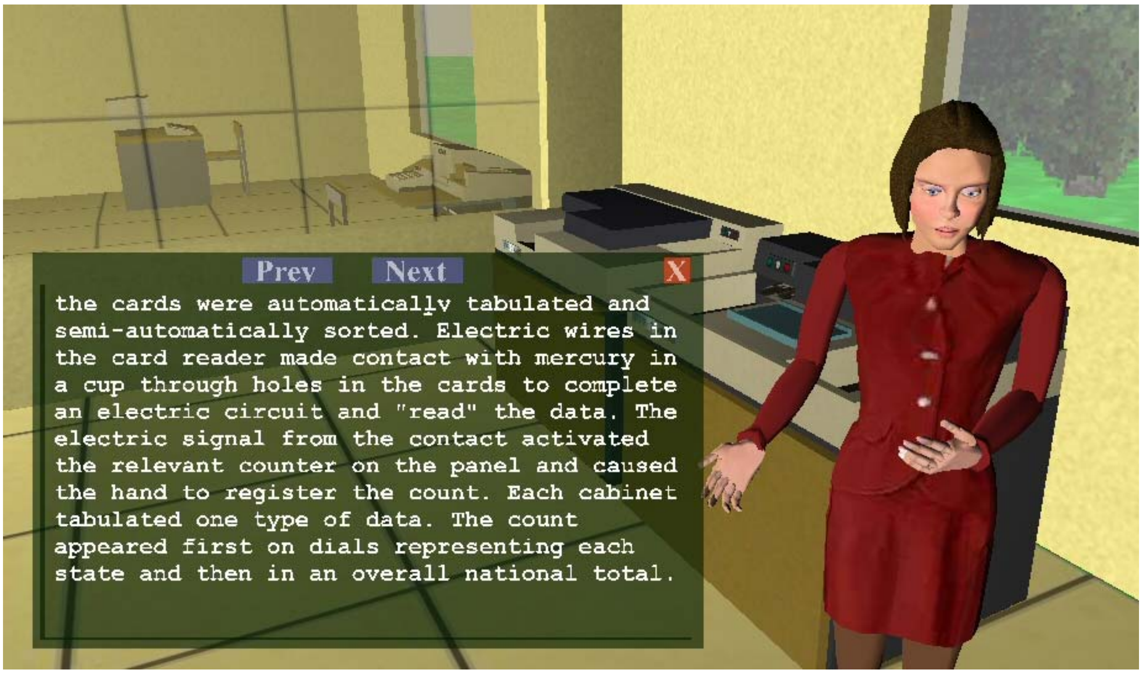

Fig. 6: The required presentation text is read by a text-to-speech engine and/or displayed on a semi-transparent On-Screen Display. The virtual guide mimics a talking person.

Evaluation Setting and User Task

Interaction with the virtual environment took place through keyboard and mouse. Users could choose between mouse and the four arrow keys on the keyboard for movement inside the 3D Computer Science museum, while only the mouse could be used to point at and manipulate objects. The hardware used for the experiment was a standard 19 inches Trinitron monitor and a 2.4 GHz Pentium IV PC equipped with a Nvidia GeForce4 Ti4600 graphics board. The full screen was devoted to present the view of the visited environment.

Prior to the virtual visit, subjects filled out a brief demographic questionnaire. Next, they were instructed about how to interact with the application via keyboard and mouse, using a simple training environment (two connected rooms with objects that can be clicked and moved).

After completing the training phase, the virtual visit started. Subjects were asked to freely wander around the museum and get information about the displayed objects of interest. After entering the museum, they were free to choose whether to follow the embodied agent on a guided tour, which gave a general introduction to the subject and was composed by 9 presentations of museum items, or visit the museum freely. At any time, visitors had the option of abandoning the guided tour (by simply not clicking on the guide after a presentation) or resuming a previously abandoned tour. We explicitly told subjects that following the guide was optional, and that they could obtain the same information by freely exploring the museum and clicking on the museum items.

All users' interactions with the application were logged. In particular, we recorded: (i) each user's path in the virtual environment; (ii) each interaction with the virtual guide (i.e., each click on the virtual guide to continue the tour with the next museum item); (iii) each interaction with museum items (e.g. request of information, opening of cabinets).

After the virtual visit, the subjects filled out a second questionnaire, where they were asked to rate the ease of use of the system and their impressions of the virtual guide. Finally, users were interviewed (using a semi-structured interview protocol) to determine strengths and weaknesses and collect suggestions.

Results

From the point of view of guide usage, 19 out of 20 users chose to exploit the virtual guide (i.e., they requested at least one presentation to the guide). The average number of requests of presentation per user was 6 (out of 9 possible presentations), indicating a considerable exploitation of the guide functionality. It is interesting to note that users with no experience of 3D environments requested more presentations, while users with good familiarity with 3D environments requested less presentations (see

Figure 7). With respect to guide usage, there were no differences related with gender, age, and duration of visit.

Figure 8 visualizes the users' flows on the virtual museum map. Black areas represent the museum building, items and furniture; the white/grey color identifies the areas visited by users (the darker the shade of grey, the longer the time users spent in the area; the white color represents areas where the user spent less time); areas painted with diagonal stripes indicates the positions over which no user stood. Dots represent locations where the guide presented a specific item (in the order given by the numbers in the figure), while black thin lines highlight the guide path along the tour. It is interesting to note that some presentation locations (i.e., 1, 2, 3, 4, 6, 8) correspond to or are very close to highly visited areas, while this is not true for other presentation locations (i.e., 5, 7, 9), which are in areas not easily accessible by users. This indicates that users tend to avoid places where it could not be easy to find a way out (e.g., corners), and highlights the usefulness of the guide in presenting items that would go probably unnoticed because their position is difficult to access.

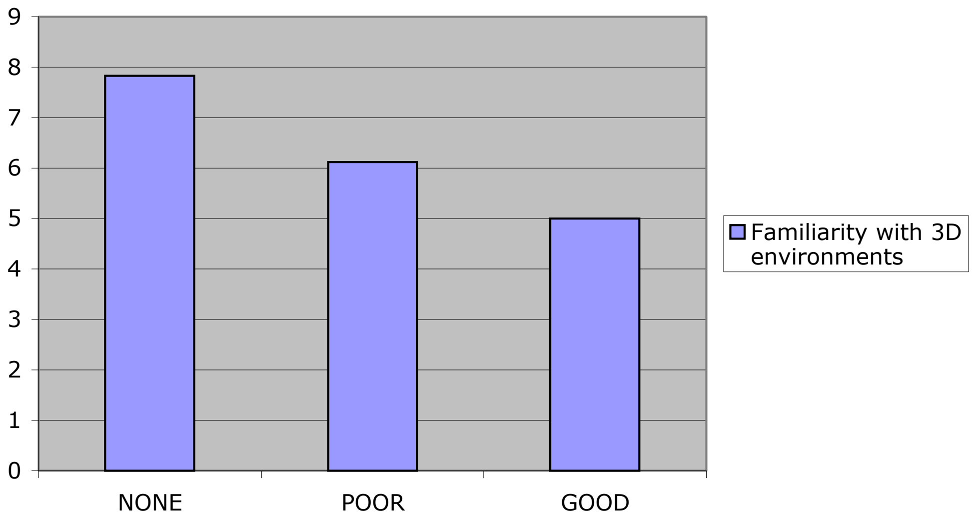

Fig. 7: Average number of presentations requested to the guide by users with none, poor and good experience with 3D navigation.

The users' answers, collected in the questionnaire, are summarized in Table 1. Users were asked to rate the easiness and appeal of the interaction with the system, and the usefulness and walking speed of the guide. While most users found the interaction easy, and rated the virtual guide as useful, reactions to the appeal of the system and the speed of the virtual guide were mixed.

During the final interview, we focused on problematic aspects of the guide and obtained suggestions. In particular:

- **we asked users if and how the virtual guide had been of help during the visit**. Interestingly, users that positively rated the guide declared either that the guide had been useful as a navigation aid (in particular, at the beginning of the visit), or that they had preferred to make a first exploration by themselves, and later used the guide for its ability to present the museum items in a logical order.

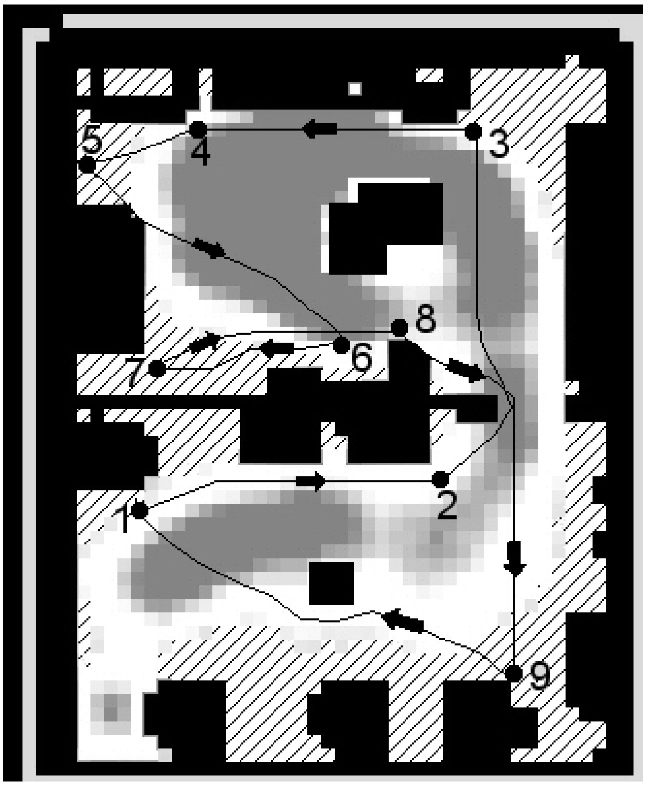

Fig. 8: Users' flows in the virtual museum during the evaluation; black areas represent museum building, items and furniture; white/grey represents areas visited by users (darker shades of grey correspond to areas of the environment where users spent more time), dots are locations of presentations of the virtual guide, lines connecting the dots are the paths followed by the virtual guide. The small dark grey area in the bottom left corresponds to the location where the visit started.

- **we asked users to rate the usefulness of the features of the virtual guide**. While many users simply said that the guide was useful, others complained about the walking speed of the guide (too slow or too fast), the talking speed of the guide (too slow or too fast), and some users were not satisfied with the appearance of the guide (some in terms of realism, e.g. lack of facial animation, and some in terms of preferred appearance, e.g. some would have preferred an aesthetically better agent).

we asked users to provide a wish list for the virtual guide. Some users pointed out that the guide was useful to first-time visitors, but they were not likely to use it in a second visit, unless it was able to provide a different tour. Other users pointed out that, in some cases, the presentations were boring, because they explained things they had previously learned by freely visiting the museum. Finally, a few users would have liked the ability for the guide to interact with museum items (e.g. open cabinets, push buttons, etc.).

User evaluation question	1	2	3	4	5
How would you define the interaction with the system? (1 – difficult, 5 – easy)	0%	0%	30%	40%	30%
How would you define the interaction with the system? (1 – boring, 5 – exciting)	0%	5%	45%	30%	20%
How would you rate the usefulness of the guide? (1 –useless, 5 – very useful)	0%	0%	15%	20%	55%
How would you rate the walking speed of the guide? (1 – slow, 5 – fast)	0%	20%	50%	20%	0%

Table 1: Evaluation results from the post-experiment questionnaire.

6. Conclusions

The results of the evaluation confirm other empirical studies (e.g. (Lester et al. 1997), (Towns, 1998)) on the positive effects that embodied agents have in the context of presentations, and in making a virtual place more lively and attractive for the user.

As a navigation aid, the embodied agent proved to be appreciated in the evaluation. It was mostly rated as simple to use, and it had the advantage of being unobtrusive for the expert user. Moreover, using the embodied agent demanded a very short learning time, probably because, from a human-computer interaction point of view, the guide metaphor has the advantage of being consistent with the real-world experience of users.

By analyzing the most frequent concerns expressed by subjects, there is a clear need for personalization capabilities. For example, walking and talking speed of the embodied agent were both rated too slow or too fast by some users: the ideal solution would be to adapt these features on the basis of each single user's preference. The visual appeal of the guide is also presumably dependent on each single user. Other concerns require more complex adaptation capabilities, e.g. the ability to adapt the explanations given in the tour on the basis of what the user previously did in the museum, or the ability to propose different tours in the case of multiple visits.

From this point of view, automating the process of deriving a guided tour for a 3D virtual environment opens up the possibility of building programs that dynamically generate different tours for different visitors, taking into account what is known about user's preferences, interests, and needs. In particular, the VRML Tour Creator can be integrated into any architecture that is able to dynamically generate VRML content, such as (Chittaro and Ranon, 2002; Walczak, 2002). The architecture we have recently proposed, called AWE3D (Chittaro and Ranon, 2002), explicitly supports the recording of usage data inside the VRML virtual environment and is thus well suited for personalization purposes.

With respect to future goals of this project, besides considering adaptivity, we plan to extend the possible functions and behaviors of the embodied agent. This ranges from the possibility of having users give high-level commands to the guide (e.g. "tell me more about this object", "I'm not interested in this object") to extending the guide abilities in interacting with the virtual environment, e.g. open doors and operate with interactive objects. Finally, we plan also to experiment the embodied agent approach in a wider virtual environment than the relatively small museum presented in this paper, thus exploring more deeply the relations between virtual environment size and use of the embodied agent.

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