Integration of Virtual Reality and Database System Techniques

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Abstract. In this paper we discuss issues concerning the development of interactive virtual reality (VR) environments. We argue that the integration of such type of environments with database technology has the potential of providing on one side much flexibility and on the other hand of resulting in enhanced interfaces for accessing contents from digital archives. The paper also describes a project dealing with the dissemination of cultural heritage contents. Within the project an integrated framework has been developed that enhances conventional VR environments with database interactions.

1 Introduction

In the last ten years, virtual reality (VR) technologies have been the focus of intense developments, also because of the increased availability and accessibility of dedicated hardware platforms and of fast advances in display technologies. VR techniques have also been successfully applied to different domains, such medicine, architecture, chemistry, education, entertainment. One of the most useful characteristics of a VR-based approach, shared by all its applications, is the possibility it offers to look at the objects of interest from multiple viewpoints, usually not available in normal conditions. For example, an architect can visit the building he/she has designed before the construction; a pilot can be trained through a simulation without actually flying.

Research opportunities related to the VR world are steadily growing in number. Recently, VR has attracted the interest of researchers as a new and powerful tool for enhancing human interactions with databases and digital archives. In particular, the application of such technology is very promising in making the access to digital archives easier and more attractive and the visualization of their contents more effective. Even though current database systems typically provide a large number of different interfaces, ranging from the direct use of SQL language to form-based interfaces and to application-specific interfaces, interacting with a database requires some skills in using computer systems. We are still far from being able to provide users with tools which are natural for them to use. However, the main drawback is that those interfaces are not particular attractive. This is an obstacle to a wider use of database

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systems and digital archives as sources of information for a large variety of users, from children to senior citizens. Moreover also the interpretation of query results can be problematic, especially for the less skilled users. We believe that results should be displayed in terms of presentation objects that are related to the semantics of retrieved information. We need very much tools able to provide the equivalent of the desktop metaphor for database systems and digital archives. A main requirement characterizing database systems and digital archives is however that the metaphor should involve objects semantically related to the actual information contents. Thus, metaphoric presentations should be dynamically generated based on query results.

We believe that VR is an important element in achieving the above goals. It can be applied to create environments that, by hiding the complexity of the underlying databases and archives, are more comprehensible to users and make easier for them to interact with the system. Not only a VR approach can simulate the real world to which the stored information are related, it also offers possibilities to customize contents that are very difficult to achieve in the physical world. For example, if a database contains information concerning a digital library, we can think of developing a virtual library showing the books a user is interested in. In such a case, the user can easily browse the information, because she/he can interact with objects that belong to his/her personal experience and which are characterized by well-known properties and behavior. We can think that a customized library can be built for each user, based on his/her interests, the tasks he/she is involved in, the past access history. We believe that by mapping the information retrieved from a database onto objects of the virtual world according to a well-understood metaphor one can dramatically enhance the process of acquiring new information, especially for the non-expert users.

As we already mentioned, VR techniques can be very useful also in the information visualization process. A virtual environment makes it possible to take advantage of the spatial orientation ability, innate in every human being, to browse the database in a very natural way. Moreover, one can quickly adjust the level of detail with which the information is examined by users by simply changing the point of view in the virtual space. Information visualization is also a powerful instrument for highlighting the relations linking the data. Every three dimensional object is endowed with six degrees of freedom, consisting of the three spatial coordinates and its orientation. These coordinates, combined with the objects' shape and color, can help identifying possible hidden relations and trends correlating the data. Another important property of information visualization through a VR approach is that it allows one to quickly and effectively analyze large amounts of data. This characteristic is very valuable in enhancing traditional data mining techniques. Another very promising application of VR techniques is related to the dissemination of cultural heritage (CH) contents, especially when dealing with ancient manuscripts and artifacts that need to be carefully preserved and cannot thus be made available to the general public or with environments not any longer existing.

In this paper we discuss issues related to dynamic and interactive VR environments and outlines open research issues. We focus on the use of VR and its integration with database system techniques in the framework of an application for the exploration and visualization of cultural heritage contents, developed as part the DHX (Digital Ecological and Artistic Heritage Exchange) project [34]. The project has developed a number of innovative multi-user interaction techniques and integrated a multimedia database within a VR environment to enhance the amount and quality of information provided to users during their virtual visits.

The remainder of this paper is organized as follows. Section 2 briefly summarizes current efforts dealing with the use of VR for the visualization of cultural heritage. Sections 3 and 4 discuss issues related the development of VR presentations for the domain of cultural heritage and new interaction instruments, respectively. Section 5 describes the DHX project by focusing on the approaches adopted to achieve high interactivity while ensuring reasonable performance and on the integration of a VR environment with a multimedia database system. Section 6 concludes the paper and outlines future work.

2 Visualization of Cultural Heritage – Current Research Efforts

Virtual reconstructions of archaeological excavations, museums, cultural environments have recently been the focus of many projects supported by the European Union that has devoted a lot of resources to this sector. An analysis of virtual reality systems adopted in these projects shows a large variety of adopted technological solutions, such immersive VR, CAVE, Augmented reality (AR) [7-13]. In particular, many projects are devoted to the 3D reconstruction of historical buildings, archeological sites, or other settlements of past cultures [1-6]. Other research efforts combine the real world with specific 3D graphic elements by mean of AR platforms [7-13].

Those virtual cultural heritage (VCH) environments have an increasingly important role in the conservation and interpretation of past culture; however, they are merely designed to visualize historical objects rather than to help the visitor to immerse him/herself in the virtual world to stand face to face with past cultures [14]. Historical human everyday life is as important as the level of details of the 3D model since visitors are fascinated by aspects of social life with which they can relate to and interact with. These are typically features of popular computer games [15]. In fact, some surveys have been directed to investigate the possible application of game theory to VCH environments [16-18]; a main issue here is to avoid that the user looks away from the cultural sense of the framework in order to win the game. Based on these investigations, several projects have developed VR worlds in which the visitor is immersed in a crowd simulation of some life activities [19-21], by means of virtual population, with the aim of increasing the reality of the reconstructed scene. However, results from the application of the game theory show that the system without adequate interactions or engaging storytelling can bore the visitors. For this reason, some interaction devices have been integrated in virtual reality system in order to make the scene less inert and users more active [22-26].

To summarize, we can say that the main technical drawbacks of current projects are the low interactivity and the lack of customization and adaptivity to a large variety of user classes. It is important that those systems be able to cater to a diverse, broad audience with different information needs, and also to support customized visits, possibly extended in time, on a per-user basis. From the contents point of view, VCH environments should be much richer, and provide many more details and more accurate reconstructions. Also, which content is presented should depend on the user specific information needs and context.

3 Issues in the Development of VCH Applications

The design and deployment of effective VCH applications requires first of all interdisciplinary development teams, which should typically include domain specialists whose main task is to gather and validate historical data, graphic designers and modelers to develop textures and 3D models, computer science specialists to optimize the data management process, and communication experts for the dissemination aspects. By exploiting such a large interdisciplinary body of expertise it is possible to develop virtual reconstructions with scientific foundations and suitable for both specialist and educational uses. The work of such teams needs however adequate support in terms of tools and repositories to enhance the development process.

Moreover it is important to complement the virtual world with a database containing information about geometries, textures, 3D objects, but also connected to the reconstructed environment. For example, it is very useful to know how a particular element was reconstructed and by whom, the historical sources from which information about the element has been acquired, and the hypothesis made during the reconstruction. It is therefore is important to enhance the virtual environment with an information repository containing all information pertaining to the VR objects and the reconstruction processes.

Several European projects have investigated approaches to represent the semantic historical and cultural contexts of a virtual environment; this is the case of the ARCO and the SCULPTEUR projects. These projects have developed ontologies for cultural assets, in order to define metadata able to describe 3D objects and their digital representations. These sets of metadata are based on different international standards, such as CIDOC and DUBLIN CORE. However, additional elements must be defined in order to describe new data types used in 3D environments.

Besides creating a VR environment accurate from a historical point of view, it is important to be able to generate and then to dynamically modify the virtual world according to the user needs and wishes. In several projects, such as CINECA, 3DMurale, ARCO, such processes are made possible by connecting the 3D world to a relational database. Unfortunately, the variety and the personalization of the possible queries are limited by VR environments that are not dynamically modifiable in their geometric structure. This problem could be solved by making parametric the environment itself, so that it can be modified according to the number and the types of the three-dimensional elements to visualize. Such a system would support a rapid prototyping of VCH applications. This is the approach taken by the CiVeDi system [35]. Such a system includes a repository of multimedia objects, implemented by a relational database; the VCH designer specifies through queries the objects to be visualized. The system automatically generates a VR environment including only these objects. The designer can also specify clustering criteria according to which objects are placed in the virtual world.

4 New Interaction Instruments

For a more effective dissemination of VCH environments it is important to develop new interaction devices enabling the users to query the environment without leaving the immersive context. The use of devices like pc or palmtop is likely to distract the user, bringing back her/him to the reality. Alternative or complementary elements, like replications of theatrical machines or pointing devices masked by magic wands, can represent more natural instruments to use. Moreover the integration of vocal recognition equipment would represent an important enhancement to VR environments. By using those devices users would be able to directly communicate with the virtual guide, for retrieving additional information or customizing the VR presentations.

Besides investigating innovative interaction devices it is also important to introduce the concept of "storytelling". As the computer game literature teaches, in order to develop applications that do not bore the player, it is necessary to conceive engaging and highly interactive scenarios. Several investigations have been carried out in order to integrate computer game techniques in cultural contexts. Everyday life moments, reconstructed historical events, environments that remember the passage and the choices made by users, the adoption of alternative pointing devices are only a few examples of how to create engaging environments that correct from a historical point of view.

Obviously the use of interactive VR systems and the adoption of innovative interaction devices require addressing the performance problems related to real time generation of immersive scenarios. Performance issues include: the development of approaches that are a compromise between high precision models, but computationally very expensive, and models with a less detailed geometry, but that can be easily and efficiently integrated in virtual environments; the development of efficient techniques for illumination, an extremely important element for a realistic rendering of the environment, but at the same time particularly onerous in terms of real time computation; the development of articulated and yet efficient user interaction techniques, supporting for example object selection and positioning by users, changes to textures, and adjustments to the lights in real time.

5 The DHX Project - A 3D Virtual Theatre

The goal of the DHX project is the development of an infrastructure for promoting the sharing and the use of the European cultural heritage, through the virtual reconstruction of sites relevant from an artistic or naturalistic point of view. As part of the DHX project, supported by the EU, we have developed an interactive digital narrative and real-time visualization of an Italian theatre during the 19th century. This project illustrates how to integrate the traditional concepts of cultural heritage with VR and database system technologies. Novel multimedia interaction devices and digital narrative representations combined with historical and architectural environments scientifically accurate offer users a real-time immersive visualization where to live experiences of the past.

One of the most characteristic aspects of the Italian social and cultural life during the 19th century was an intense and widely spread theatrical activity. During this period, in Italy as well as in the rest of Europe, going to theatre was one of the most common amusements for both the aristocracy and the common people. Only in the city of Milan, there were about 20 theatres of different sizes, where more than 1000 companies used to play. However, whereas the amount of information and documents concerning such theatrical activities is quite relevant, most of the buildings are no longer available and the ones still in place have undergone extensive changes over the years. This is the typical situation in which VR techniques can be effectively applied to propose contents otherwise impossible to access. In particular, our application aims at reconstructing an Italian theatre of that period, thus making it possible to appreciate again the original structure and appearance of such theatre. It is important to remark that our theatre is not the reconstruction of a real building, but an historically correct model, obtained by combining features of several Italian theatres. In particular, we set the reconstruction in the middle of the 19th century, and we paid particular attention to choose only those elements compatible with that time. Since technological, artistic and social changes were at that time much slower than nowadays, in some cases elements of the first part of the century can coexist with features of the second half of the century.

5.1 The 3D Model

For our model, we adopted the plan of the Canobbiana theatre, which share, with the other theatres of the period, the "all'italiana" structure. By using a 3D commercial software, "ArchiCAD", and based on the Canobbiana planimetries and elevations, we reproduced an early structural component of the scenes. The ArchiCAD model, although correct from a spatial and dimensional point of view, was imprecise with respect to the polygons arrangement. For example, we had overlapping walls, uncompleted architectural structures, and a very large number of polygons. To address this problem, almost all of the structures and architectural components were manually re-modelled in "Alias Maya"[27] using the space-dimensional references derived from the ArchiCAD measurements. Maya offers a fully integrated solution to address a complete VR system and provides some common methods to keep the application frame rate appropriate for a real-time interactive simulation.

Because our model was to be integrated in a VR environment, we were particularly careful with respect to performance in order to assure a pleasant visualization for users. The complexity of the model geometry, as well as the texture sizes and the amount of scene-specific objects are critical elements in determining the time required to render a scene. To maintain the appropriate frame rates and real-time interactions, it is best to use polygonal geometry to build the models. This technique requires less data than the data required by the use of NURB (Non-Uniform, Rational, B-spline) geometry. A NURB surface is a smooth interpolation surface that allows one to define curved forms that are not faceted, but “really” curved. However, a polygonal model supports a faster rendering calculation, since it is much less complex than a model build with NURB techniques. Furthermore, the use of primitive shapes as basis for building new elements and the cutting of unnecessary faces are useful practices to decrease the number of polygons and the time required to evaluate a surface during the rendering phase. Other methods for the development of the 3D models for real time visualization are the division of the scene into several overlapping modules and the use of the softening edge technique. The first strategy allows one to export single modules into different files, and to load them only when needed, thus achieving a better frame rate. The second technique allows one to show adjacent flat faces smoother along their surfaces during the computation of the shading representation, in order to use geometrical elements with fewer polygons. Colors, materials and textures covering the model were realized with the goal of creating a photo realistic effect. For example, we used the light mapping technique to calculate the correct lighting of every part of a scene; we then converted it into simple textures and applied it to the geometry. By following those techniques, we were able to develop a model compatible with the real time generation of immersive VR scenarios.

5.2 The Virtual Reality Framework

The main purpose of a VR system is to immerse the user in an artificial environment generating the illusion to be into a real world environment. In such a semi-immersive system, users are placed in front of a large projection screen equipped with a stereo surround system [28-31]. By wearing a pair of stereo glasses, users have the feeling of being immersed in a virtual environment. Our application can be displayed on a semi-immersive visualization system, composed of a couple of projectors, a rigid screen for back projection (size of 2,80 x 2,00 meters), a graphic workstation and a pc/touchscreen for managing the user interactions.

The application is implemented with Avango [32-33], an object-oriented framework for the development of distributed, interactive virtual reality systems. Avango is based on SGI Performer, the programming interface oriented to the development of real-time visual applications. All the advanced rendering tasks like culling, level-of-detail switching and communication with the graphics hardware, are handled by Performer. Whenever the underlying hardware allows, Performer utilizes multiple processors and multiple graphic pipelines. New functions can be implemented by subclassing and extending the existing Avango classes, which are written in the C++ programming language. In addition to the C++ API, Avango is characterized by a language binding to the interpreted language Scheme, a general purpose programming language deriving from Lisp. All high-level Avango objects can be created and manipulated from Scheme. An application is then just a collection of Scheme scripts which instantiate the desired Avango objects, call methods on them, set their field values and define relationships between them. The Avango objects are included into the nodes of a tree graph named scene-graph, which is the Perfomer data structure maintaining the information that defines a virtual world. A central concept in Avango is the concept of shared scene-graph, which is accessible from all processes composing a distributed application. Each process owns a local copy of the scene graph and the contained state information which are transparently synchronized with respect to the user. The distribution system is based on the use of a memory segment shared among the processes taking part in the application. Objects allocated into such a shared memory segment become visible to all participating processes.

5.3 The Virtual Tour

The main goal of our application is to make it possible for end-users to acquire new knowledge concerning the Italian drama theatre in the 19th century through the exploration of the virtual reconstruction of a typical theatre of the time. As we already mentioned, in order to make the exploration of the virtual world more engaging for the users, it is useful to organize the visit around a story. In our case, the story is centered on the interaction between the user and a virtual character met when the visit begins. The virtual character, symbolizing the spirit of the theatre, is looking for a talisman he lost somewhere in the building; the talisman controls the magic responsible for the success of the performed plays. The user, going along with the virtual character in the search, has the opportunity to learn the story and the most interesting features of the theatre. The virtual character performs the role of a guide, describing the environment and giving additional information if required. He also gives the user the opportunity to make choices concerning the contents of the visit. For example, in the central box, the virtual character asks the user to choose among the available plays to see one played on the stage.

The tour begins in the theatre's hall, where the user encounters the virtual character. Then they visit the stalls, the central box and, if the user is interested, a common box. The visit continues on the stage; here the user can interact with the theatrical machineries. In the end, the virtual character finds the talisman and the tour ends. The virtual character resembles Meneghino, a typical mask of the Commedia dell'Arte, the Italian ancient masked comedy born in the Renaissance and performed until the first half of the eighteenth century. Its model, developed in Maya, has the appearance of a puppet in order to accentuate its fantastic nature. The character can perform a set of gestures, developed as Maya animations and loaded into Avango. Lip synchronization with the speech is also supported.

5.4 The Interaction Framework

The core of our system is the interaction framework which includes a database system. Our VR environment makes available to users various methods to retrieve information from the database. The main method is the dialogue with the virtual character. The tour is organized according to specific steps defined by the underlying storyline, in which the guide has a crucial role. During the visit, the guide can establish a dialogue with the end-user in order to satisfy her/his curiosity. This communication method is controlled by a message board, called InteractionBoard. The InteractionBoard is accessed by means of the touch screen of a PC installed in the VR platform. The message board is triggered depending on the position of the visitor. Following a predefined dialogue structure, the guide can deal with a particular theme, either in details or according to an introductory style. The choice is up to the visitor who, by clicking on the screen, can use the message board to specify her/his preferences.

The InteractionBoard is also used to select the plays in the central box and to retrieve information about some objects placed in the environment. When the guide describes an artifact, further information is visualized on the InteractionBoard. According to the same approach, objects that are not directly connected with the guide talk can trigger an information box on the PC screen when the visitor gets closer to them. The interaction framework is complemented by special devices reproducing theatrical machineries of the 19th century. Starting from the historical information gathered from the Piccolo Teatro di Milano, which still preserves real examples of those devices, virtual machineries have been built and integrated into the theatre. For example when the user visits the backstage, she/he has the possibility to activate a wind machine to learn how, during the 19th century, the noise of the wind was simulated using this device. In order to interact with the virtual reconstruction, a real machinery, with the same size of the original one, has been built. When the user starts turning the real handle, the virtual machine turns as well. Such machinery is designed to offer to the users a new, more intuitive tool to interact with the environment.

5.5 The Multimedia Database System

To be able to answer user requests for additional information during the visit, we have included in our system a component supporting user queries against a multimedia database (see Figure 1). The core of such component is a relational database built on Oracle technology. It is articulated into four main content components related to various aspects of the theatrical activity in Milan during the 19th century: theatres, theatrical companies, performances, and documents published in the newspapers. The database also contains a variety of multimedia data, such as images, theatre maps, scene costumes and audio/video reproductions of parts of the performances.

The historical data have been collected by researchers from the Department of Performing Arts of the University of Milan. However, the data collection process is

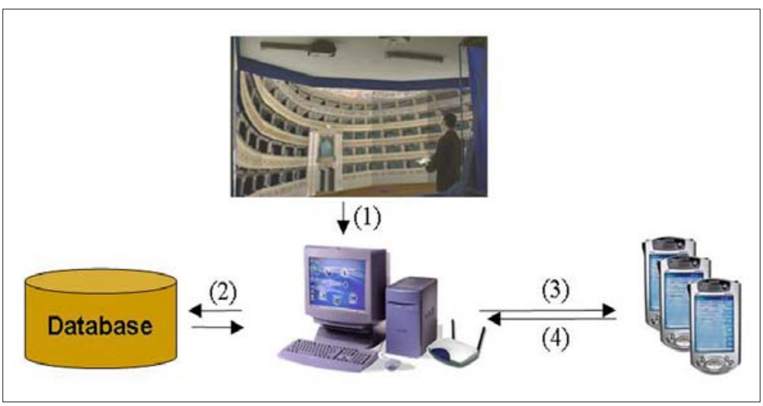

Fig. 1. DB and VR interaction

still going on. Visual and textual data are constantly growing in number because of new discoveries of theatre images, actors' and playwrights' portraits, play-bills and, in particularly interesting cases, letters, contracts or any other documents. The use of a multimedia database as the core of our interaction system makes however possible extending the database contents without having to modify the VR environment. The most difficult problem is represented by the collected images, since they are not usually in a good preservation state. As far as audio data are concerned, obviously there are no tracks from the past, so that it is necessary to mix past and present: our solution is to let young actors read the best passages from the once most famous, but nowadays often completely forgotten, plays.

Such a large amount of information must be smoothly integrated in the VR environment. A solution we have adopted is based on the use of a palmtop or of the InteractionBoard to allow users to formulate database queries in order to obtain further information about the environment. When a user is closer to an important object or the virtual guide is describing a particular place, information is loaded into the interaction-board or into the palmtop. In addition by using these devices the user has the possibility to explore the database in order to retrieve additional interesting information; for example in some places of the theatre she/he can listen or watch to several audios or videos reproducing pieces of dramas or operas from the 19th century.

6 Conclusions and Future Work

In this paper we have discussed issues concerning dynamic VR environments for the dissemination of cultural heritage content. We have also briefly described an application related to the presentation of a typical Italian drama theatre of the 19th century.

Future developments are addressed to offer an improved integration of the database system in the VR environment. In our suggested solution the 3D virtual tour is integrated with an additional tool: a database application used to obtain further information about what the user can see during his virtual reality experience. But, probably this method spoils the user's feeling of being immersed in the reconstructed environment because his attention is shifted to the database application placed either on the palmtop or on the InteractionBoard. For this, we are investigating other techniques for supporting database queries in VR environments.

To make the visit even more engaging we are also considering the introduction of new theatrical machineries and the extension of the application to support multi-user interactions. Multi-user interactions are addressed to create a shared virtual world where remote co-players can meet and interact in the same virtual, three-dimensional environment. The DHX consortium is evaluating and testing multiple techniques to integrate multi-user features in the AVANGO framework. Finally, we are investigating the extension of the InteractionBoard with voice-input to allow the visitor to control the dialogue by directly speaking to the virtual guide.

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