A GENERAL FRAMEWORK FOR REPLICATED EXPERIMENTS IN VIRTUAL 3D ENVIRONMENTS

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Abstract: This paper reports on a parameterizable 3D framework that provides 3D content developers with an initial spatial starting configuration, metaphorical connectors for accessing exhibits or interactive 3D learning objects or experiments, and other optional 3D extensions, such as a multimedia room, a gallery, username identification tools and an avatar selection room. The framework is implemented in X3D and uses a Web-based content management system. It has been successfully used for an interactive virtual museum for key historical experiments and in two additional interactive e-learning implementations: an African arts museum and a virtual science centre. It can be shown that, by reusing the framework, the production costs for the latter two implementations can be significantly reduced and content designers can focus on developing educational content instead of producing cost-intensive out-of-focus 3D objects.

1 INTRODUCTION

Web-based 3D applications are very popular in the learning, commercial and entertainment sector. Despite the success of these products, the cost of designing and producing content-rich 3D learning environments is still a major issue, especially if realistic models, non-deterministic simulations and special user interaction are required.

Our work focuses on the production of learning content with a high degree of interactivity, photorealism, reversibility and non-deterministic simulation models, which allows learners to understand the design and methodology of an experiment through an individualized, interactive, Web-based application (Biella and Luther, 2007).

In a recent interdisciplinary project concerned with the historical replication of interactive key experiments in psychology and education, 2D and 3D implementations of B.F. Skinner's historical experiment on operant conditioning were implemented, tested and evaluated by students (Biella, 2006). Results showed that

- the 3D version effected a higher degree of spatial and cognitive immersion,
- the 3D visualization of the experimental setup was more realistic in terms of graphical quality,
- users tend to accept mixed (2D and 3D) content despite media discontinuities in favor of knowledge creation,
- the experiment was easier to comprehend in 3D.

The question of whether to use 3D or 2D depends on the design requirements, the target user group and the model data to be presented. Design considerations are listed in the section "Modelling pipeline" and discussed in the section "Discussion".

This paper reports on a parameterizable 3D framework for Web-based experiments and identifies reusability options.

It highlights three case studies that prove the feasibility of the concept and its cost efficiency, and gives an overview of recent work to enhance the framework.

2 MODELLING PIPELINE

The modelling pipeline for replicated experiments in virtual 3D environments presented by Biella (Biella, 2006) includes a general framework and several workflow components that are suited for reusability (Figure 1).

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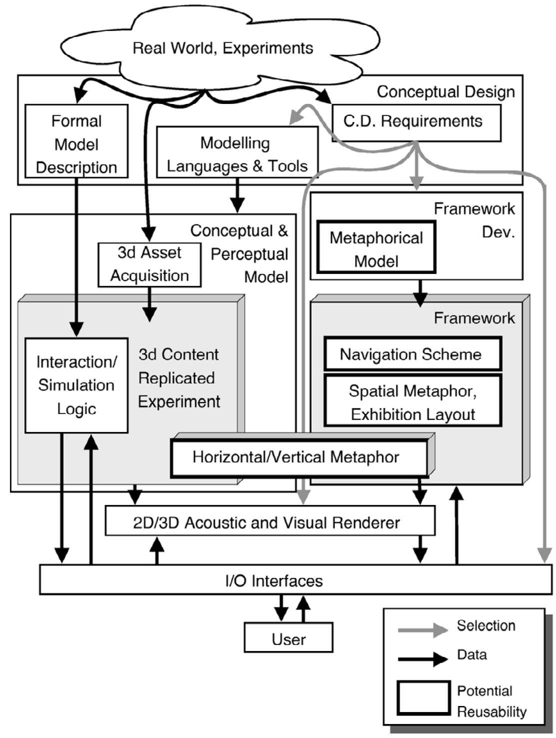

Figure 1: Reusability options of the framework within the modelling pipeline.

Initially, a real-world experiment is analyzed from an authentic setting or from primary and/or secondary sources with a focus on the 3D geometrical model of both the experimental assets and the historical surrounding, an animation model, an interaction model, and an simulation model.

The input/output hardware interfaces and drivers, the rendering software, the modelling languages and tools, and, optionally, a framework development for the integration of multiple experiments are determined by specifying conceptional design requirements that depend on the target user group and the complexity of the geometrical, interaction and simulation models.

The formal model description describes the process of defining the animation, interaction and simulation models in abstract notions, such as mathematical functions, statistical models or state machines. These models are digitized by using suitable model description languages, such as unified modeling language (UML). The implementation of these models (Interaction/Simulation logic) depends on the programming and scripting languages determined as a result of the conceptional design requirements.

The following design considerations have been formulated in (Biella, 2006) with regard to Web-based museums for replicated experiments.

- Historical context representation: Although 2D visualizations may suffice for the presentation of an abstract theoretical model, the visualization of a historical laboratory environment is challenging. In a 2D visualization, such information has to be provided separately through additional sources, such as a sequence of photographs or text descriptions. A 3D model allows the designer to integrate contextual information in the space surrounding the experimental setup.
- Impact of occluded surfaces: Surface occlusion of objects with crucial functionalities within an experimental setup can disturb the knowledge transfer. In this case, 3D implementation must offer sufficient viewpoints or other techniques (for example, surface transparency).
- Implicit 3D experiments: Experiments that involve implicit 3D setups are best suited for implementation based on geometrical modelling and free real-time user navigation.
- Model complexity: Animation, interaction and simulation models vary in their degree of complexity and may require high-level programming languages instead of common Web-based scripting languages.
- I/O Interfaces: Input/output interface requirements must be defined according to user's perception channels.
- Data format consistency: A set of multiple 3D worlds should be implemented in a consistent data format.

3D model asset acquisition describes the process of gathering 3D raw data usually by 3D scanning or 3D reconstruction. The post-production of 3D data implies storage of high-definition 3D data in a flexible file format (e.g.: X3D, XML), polygon and texture size reduction and export in a Web-based data format, as defined in the conceptional design requirements. Both Web-compatible logic and the 3D model represent a single replicated experiment (3D content).

The presentation of multiple experiments requires the development of a metaphorical model, which defines a navigation scheme, spatial metaphors, and an exhibition layout. With regard to a (real world) building metaphor, experiments are connected through vertical and horizontal metaphors that represent thematic and temporal selections of experiments and allow the user to navigate between them.

Cost-efficiency aspects with regard to the creation of particular 3D exhibits suited for learning have already been presented (Biella and Luther, 2007).

The virtual laboratory realization presented here underlines the feasibility of the theoretical approach and stipulates that the production cost of 3D content could essentally be reduced by code reusability.

In this paper, we want to focus on reusability aspects of the surrounding museum framework, which is intended to allow 3D content designers to efficiently create several standard 3D museum assets, so they can focus on actual content development, especially for Web-based learning museums and virtual science centres. The modelling pipeline, the framework and reusability options are depicted in Figure 1. They concern the spatial design, including lighting and texturing, interaction logic, navigational schemes and spatial or temporal metaphors.

3 THE FRAMEWORK

The framework for the replication of experiments in virtual environments (referred to below as the Replicave framework) was first developed for an interactive virtual museum for key historical experiments and is implemented in X3D and PHP (Biella, 2006). It features both pre-defined and partly parameterizable routines for the automated generation of an entrance hall, a gallery, a multimedia room, graphical user interface (GUI) components and metaphor-based connectors leading toward the laboratory rooms in which the interactive experiments are located.

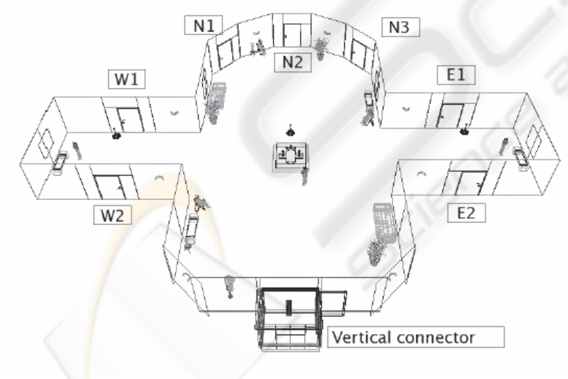

Figure 2: Conceptional metaphor with maximal number of laboratories (wireframe view including position descriptors).

The framework references a real-world building metaphor. Basic framework assets are visualized as building parts at the ground-floor level. Content-related locations can be accessed through metaphorical connectors (Figure 2). A connector's X3D code consists of static and dynamic 3D objects that are combined into a single X3D scene graph. For the dynamic placement of thresholds, seven positions (N1-N3, E1, E2, W1, W2) are reserved to which laboratory doors, a small media room door or walls are allocated according to a certain layout matrix. The dynamic generation of the wings is achieved by including static X3D code fragments that define either a wall, which renders the wing's entrance closed, or the full wing layout.

In analogy with the building metaphor, the temporal metaphor is the vertical connector. On each level, the doors of this allocation place form a meta-threshold and give access to meta-paths. The desired path and destination threshold is defined by the user's selection of a different content or experiment on an appropriate navigation panel. The panel is rendered dynamically at runtime and lists all available presents.

3.1 Entrance Hall

As the user's initial starting point in the 3D world, the entrance hall is an obligatory asset. By default, the main hall is cylindrical with a transparent domed ceiling. The design is intended to reproduce the atmosphere of a modern museum building located in an urban environment, which is visualized by a blue sky texture and externally placed building fragments that suggest the urban context (Figure 3).

Figure 3: Entrance hall (with 3D data progress indicator).

The exit door and the thresholds leading toward the main media room, the gallery, and the vertical connector are exclusively and equidistantly connected to the entrance hall, virtually dividing it into four quarter pie sections. The reception desk, with a receptionist's avatar and a login terminal, is located in the section between the gallery and the metaphorical connector. Dynamically generated information panels listing the available experiments are located at the reception desk and in the elevator (Section 2.5).

The three other sections are decorated with items that underline the context (research-related images) and 3D furniture objects.

The exit door is an interactive plane that allows the user to leave the system and that can be configured to initialize post-visit routines, such as opening a new browser window for an evaluation.

3.2 Gallery

The mainstream of psychology is presented in the gallery, which is octagonal in shape. This design allows the installation of seven information-related walls and an eighth wall that provides space for a connector to the main hall. The gallery's static 3D model defines outer walls and a transparent roof in accordance with the design of the main hall.

Large coloured information boards display the various scientific research fields following the content and colour design of an optional 2D-based timeline. 3D information plates are created by dynamic scripts and display short informational texts (for example, a curriculum vitae) and a photograph. Each plate has an interactive event sensor and an individual viewpoint configuration that allow the user to navigate there by simply clicking on them (jump navigation). The text-based content and photographs displayed in the gallery are stored separately from the multimedia content of the laboratories and the media rooms.

3.3 Multimedia Rooms

Replicave uses a two-tier approach: General multimedia content about a given topic or person (image, video, text) can be managed separately from the multimedia data that describes the virtual experiments. Hence, the framework contains pre-defined designs for two multimedia room layouts: a large central multimedia room located on the ground floor and a small layout for topic-related content.

As a result of this approach, learners can access all available 2D multimedia documents in the central multimedia room, which can serve as both a library and an appetizer for a potential 3D implementation. Furthermore, it allows content creators to integrate existing 2D content without the requirement of presenting a 3D experiment. If at least one interactive experiment is present, a small version of the multimedia room is automatically generated in the 3D content section that contains only topic-related documents.

Both room layouts share the same functional elements and visualization metaphors: For each topic or person, there is a book shelf that contains the corresponding multimedia documents represented by interactive 3D icons distinguished by their multimedia document types—book (text based document), film roll (video document) or picture frame with preview (image file).

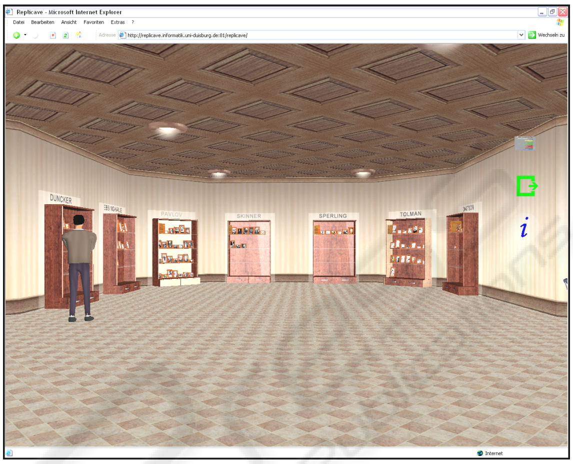

Figure 4: Central media room with dynamic 3D architectural design for multimedia content visualization.

All multimedia assets can be directly administered via a file-based document management system (DMS). The 3D icons representing the assets are automatically generated at run-time.

The parameterizable layout in the central multimedia room is achieved through an automated shelf creation, which originates in a dedicated corner of the room and is designed as a dynamically sized bulge. For large numbers of shelves (that is, topics presented in the multimedia database), it extends as a corridor of fixed width in a 45-degree angle from the adjacent static walls. This architectural design pattern leads to a library area with convex outer walls, so that the shelf objects are occlusion-free for any user located in front of them (Figure 4).

3.4 GUI Components

Replicave features the following GUI components:

- Five different 3D interactive buttons (exit, context-sensitive help, information on 3D navigation, up, down);
- Single HTML capable overlaid 2D frame.

The GUI components can be reused and individually extended in experiment-related 3D environments.

3.5 Metaphorical Connectors

Connectors allow the user to navigate between the entrance hall and content-related spaces as well as between different experiments. Two connectors are used: The vertical connector (here, an elevator) is used to navigate between the different topics, while the horizontal metaphor (here, a floor) is used to navigate between different 3D experiments on the same topic.

Dynamic content is generated in both connectors. An interactive topic selection panel in the elevator lets the user chose the desired content. The horizontal connector is based on parameterizable 3D model templates. Two templates are available: the building floor (default) and a small-scaled simplified model of the building floor that serves as an interactive 3D map.

The default template's shape depends on the total number of doors that are to be visualized. For a minimal visualization, the centre of the floor, the door leading to the small media room and one laboratory door are displayed. For a complete (maximal) layout, two side wings are added, each of which provides access to two laboratory doors, while three doors (a single media room door and two laboratory doors) are visualized opposite the elevator.

3.6 Other Assets

The framework has recently been extended by an avatar selection room metaphorically designed as a dressing room and a parameterizable template for experimental rooms (Hiller, 2007). Furthermore, new X3D nodes were created to partly replace external scripting.

3.7 The Document Management System

Replicave uses the open-source software Philex (http://sourceforge.net/projects/philex/) for the file and folder administration. It features user administration, Web-based file and folder management with basic operations, editing of text-based files, configurable access restriction regardless of file content and a user interface with tree-based folder visualization. Due to the hierarchical folder structure and multi-user support, content is grouped in dedicated folders and managed via the DMS. At least five administrator or curator roles can be deduced by setting user-specific root folders. Each laboratory or exhibition room is initially loaded by opening a script file. Specific initialization and content files offer a high degree of flexibility

4 IMPLEMENTATION

The Replicave framework is implemented in Extensible 3D (X3D) and the PHP scripting language. Interaction is implemented in ECMAScript. The system requires a PHP5-capable Web server. On the client PC, an X3D browser plug-in is required. The framework has been successfully tested with the BS Contact VRML/X3D plug-in by Bitmanagement Software GmbH and Microsoft Internet Explorer 5. The following case studies work with the BS Contact VRML/X3D plugin, version 6.2 or higher, and Microsoft Internet Explorer 7. Together with DirectX 9.0c, the high-level shading language HLSL is supported and was used for a soap bubble experiment in a virtual science centre (Hiller, 2007).

5 CASE STUDIES

The feasibility of the concept presented here has been tested in three case studies. While the Replicave framework has been reused in two implementations, the author of the third implementation decided to create an entirely new framework.

5.1 Virtual Science Center

The virtual science center contains several interactive scientific 3D experiments that refer to various mathematical theories. Users are expected to learn through interaction with virtual installations.

Hiller (2007) used the Replicave framework and showed that he could significantly reduce the production time required for framework design and visualization. Decorative 3D-objects, furniture and plants were used or slightly modified for the desk, the wardrobe and the exhibition rooms. With this savings, resources could be spent primarily on the production of learning content, and a total of five new interactive 3D experiments with simulations were developed and implemented.

First, the experiments were classified with regard to their spatial appearance, simulation model type, interaction logic and manipulation features. This will enable parts of the code to be reused to implement extensions of experiments or similar experiments, such as the brachistochrone and tautochrone problem (Figures 5 and 6).

Figures 5 and 6: Brachistrochrone—inverted cycloid versus a straight line with the same endpoints; tautochrone—the ball will take a constant time to roll to the end point, regardless of its starting position.

At first glance, visual representation of the experimental environment enhanced by avatars (Figures 5 and 6) do not deliver the outcome in the form of textual results or functional dependencies among variables written in 2D interface elements. We invite the user to find physical laws behind the experiment by watching and trying out the simulation. However, it may be worthwhile to include additional kinds of text displays or help desks in a future version.

Figure 7: "Lights on" experiment with initial 2D instruction screen.

Figure 7 depicts the "Lights on" experiment, which uses complex action logic. The figure shows a table with seven small lights and individual commutators for switching the lights on and off. However, each switch influences not only its own lamp but also both adjacent lights. The goal of the experiment is to achieve a situation in which all lamps are lit with a minimum of switching operations. This kind of experiment requires a mathematical model or an implemented action or interaction logic to enable the computer to simulate a player and to find and display the correct solution. In a recent project dealing with interactive cryptographic protocols, we developed a methodology to create a PetriStateMachine that executes the action logic of the players involved (Baloian et al, 2007). It was shown that Petri net editors and simulation engines such as Renew (available at http://www.renew.de/), support time-efficient modeling of action and interaction logics.

5.2 African Art Museum

The Replicave framework was also successfully used in an implementation of an African arts ("grassland") museum (Mafo, 2007), in which the framework's gallery assets were used as a primary exhibition space (Figure 8). Changes could be limited to adapting texture image files in order to comply with an appropriate design for the exhibition context.

Existing interaction facilities allow for manipulating 2D image-based content as well as 3D sculptures. Information panels were updated, and simple new signalling elements were introduced to help users navigate within the adapted room installation. This work could be done by any nonspecialist without deep knowledge in 3D modelling languages. Again, it has been shown that resources could be spent on the exhibition content rather than on the framework design surrounding it.

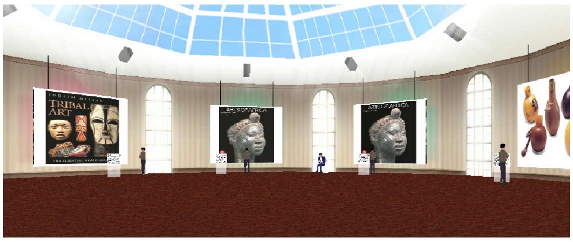

Figure 8: Gallery room in the grassland museum.

5.3 Virtual Art Museum

Unlike the two aforementioned implementations, the virtual art museum created by W. Liu (Liu, 2007) required a specific visual and geometrical framework design (Figure 9). Instead of using the Replicave framework, an individual framework was designed and implemented.

It could be shown that the framework-related work took 50% of the entire content production time, underlining the advantage of reusable framework designs.

Figure 9: Sculpture room in the virtual art museum.

At the same time, the implementation suggested possible extensions of the framework, including the implementation of a graphical editor using drag-and-drop mouse actions to modify the X3D content graph on the fly, encompassing

- spatial design,
- lighting and texturing of walls and furniture,
- modification of assets.

Such a new framework can be used to create virtual versions of existing museum installations.

6 DISCUSSION

Today, the design of virtual 3D applications is very popular, and there is abundant literature on this topic. However, the realization of virtual laboratories and museums is long and expensive. There are several papers (Kleinermann, 2006) that outline the procedure to follow in the design of a VR application and number important tools for modelling the scene, defining the objects and means of interacting with them. These papers provide a first impression, whereas the inherent complexity of the creational process makes it necessary to consult special purpose literature.

In a recent paper, Hendricks et al. (2003) report on virtual African art galleries. In a comparative study, 2D and 3D environments were evaluated. The results of the user study showed that users have a clear preference for 3D environments only if they are not too complex and provide the users with a high level of navigational support, whereas 2D settings are better suited to convey a large amount of information that exists in sequential form.

These results encouraged us to use the Replicave framework in the realization of the grassland museum. An initial evaluation with a small number of participants partly confirmed observations made by Hendricks et al. concerning interaction and 3D navigation.

3D modelling languages, like X3D, use scene graphs to build a 3D spatial design. A notion that is key to reusing code consists in rewriting the scene graph.

Unfortunately, changes in the scene graph intended to bring about a local modification of an object with respect to its geometric shape, texture or position should take into account the context of the relevant node. In Reitmayr and Schmalstieg (2005), the authors present the idea of adding a context element to the traversal states of a scene graph that allows the scene graph to be parameterized and reused for different purposes. An annotated context-sensitive scene graph improves its own inherent flexibility when acting as a template with parameters set during traversal of the graph. Using the new concepts, a general framework called "Studierstube" is presented, together with a dedicated model server component containing the scene graph of the building model and an interface that allows users to integrate already designed components into their own scene graph realizations.

Automatic generation of user-specific content is addressed in a paper by Chittaro et al. (2004) and in further papers cited therein. The authors propose a novel tool that provides automatic code generation for adding personalized guided tours to 3D virtual environments that were developed using frameworks able to dynamically generate X3D content.

7 CONCLUSIONS

We have presented a general framework for replicated experiments in virtual 3D environments that is parameterizable and reusable. The framework is embedded in a new generalized modelling pipeline that promotes cost-efficiency by reusing existing design patterns and 3D assets.

The approach was successfully applied in two implementations of interactive Web-based virtual 3D exhibitions: a grassland museum for African art and a virtual science centre. In both cases, designers were freed to focus on content development. A third implementation illustrated the significant amount of additional resources required for individual framework design without using an existing framework library.

8 OUTLOOK

A further extension of the number of parameterizable variables and a complete conversation to XML-based model and content description languages are part of ongoing research. Another focus of our future work concerns the inclusion of conversational agents in analogy to existing solutions for real museums (Kopp, 2007).

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