Web-based and Mobile Provisioning of Virtual 3D Reconstructions

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Abstract

Communication of cultural heritage by means of digital information systems has been gaining more and more importance over recent years. Interactive virtual 3D applications enable users to explore 3D virtual reconstructions in real-time, to directly interact with the contained digital cultural heritage artifacts, and to obtain insights into this data. Nevertheless, these artifacts are usually very detailed and complex 3D models that are hard to handle for end-user systems. This paper presents the concept and a prototypical implementation of an image-based, web-based approach for the communication of digital cultural heritage and its provisioning for the Web and mobile devices by the example of the project Colonia3D – a high-detail, virtual reconstruction and high-detail 3D city model of Roman Cologne. Through this web-based and mobile provisioning, complex digital reconstructions can be used, e.g., on-site to match local findings and reconstructions.

Figure 1: A high-resolution 3D reconstruction of the ancient Roman Cologne running on an iPad device using our image-based 3D provisioning approach.

1 Introduction

The communication of cultural heritage by means of digital information systems, in particular by multi-media systems, has been gaining more and more importance over recent years. Interactive virtual 3D applications provide effective means to foster and improve this communication process beyond the mere presentation of static visualizations such as pre-produced image or video data: Interactive virtual 3D applications enable users to explore 3D virtual reconstructions in real-time, to directly interact with the contained digital cultural heritage artifacts, and to obtain insights into this data.

Real-time visualization of these reconstructions (including, e.g., high-detailed and massive geometry and image data) demands for advanced, efficient data handling and 3D rendering techniques. This generally restricts the availability of complex 3D models to high performance workstations and desktop PCs -- i.e., to a rather small number of users. Particularly, such high-quality interactive 3D reconstructions cannot be provided in this manner for mobile devices and web-based applications, which inherently have to cope with limitations in storage, main memory, processing and graphics capabilities, as well as with limited bandwidth and potentially unreliable networks required to transmit 3D models and additional data. To tackle these challenges, new schemes and approaches for designing and running such applications are required, and need to take into consideration and take advantage of recent IT trends, which are conducting a paradigm shift for more and more applications towards web-based and mobile provisioning, can provide virtual 3D reconstructions to numerous users and could enable new applications and experiences in the field of digital cultural heritage.

Existing solutions are commonly based on streaming 3D scene data to web-based and mobile clients and, thus, have to cope with many of the before mentioned limitations. To overcome these, we present an approach for an interactive visualization of 3D digital cultural heritage artifacts and reconstructions that is mainly based on splitting a 3D rendering system into two components: (1) a high-performance server system that is responsible for rendering virtual 3D panoramas for a specific 3D scene and camera configuration; it encodes these 3D panoramas as multilayered G-buffer cube maps; (2) corresponding light-weight 3D clients that process and visualize these cube maps to partially reconstruct the 3D scene and to allow users to operate on and interact with that visual representation. Key characteristics of our approach include that (a) the complexity of transmitted data does not depend on the 3D scene's complexity, (b) 3D rendering can take place within a controlled and a-priori known server environment, (c) crucial 3D model data never leaves the server environment, and (d) a client can flexibly extend the 3D cube map viewer by adding both local 3D models and specialized 3D operations.

This paper presents the concept and a prototypical implementation of this image-based, web-based approach for the communication of digital cultural heritage and its provisioning for the Web and mobile devices by the example of the project Colonia3D (Figure 1) – a virtual reconstruction and high-detail 3D city model of Roman Cologne, which is the result of a joint research project of the Archaeological Institute of the University of Cologne, the Köln International School of Design (KISD) the Cologne University of Applied Sciences, the Hasso Plattner Institute at the University of Potsdam, and the Cologne Romano-Germanic Museum (RGM).

Our approach for the provisioning of high-quality and interactive 3D reconstructions enables modern spatial user interfaces to digital cultural heritage data. In this way, it can help to improve existing applications and use cases, and facilitates the development of completely new ones. For example, virtual reconstructions and its underlying data can be “carried around” (e.g., in a museum or exhibition), can be used on site (e.g., for comparing reconstructions with today’s outdoor scenes) or can be easily integrated into specialized workflows and existing IT information systems such as web portals. Also, this approach lowers the entry barriers (regarding, e.g., necessary hardware and software to operate the 3D reconstruction) to use virtual 3D reconstructions and therefore allows higher numbers of users - experts as well as non-experts – to utilize customized content and high-quality graphics for gaining insights into cultural heritage datasets.

2 Related Work

Colonia3D, the use case presented in this paper, is a high-detailed virtual 3D reconstruction of the Roman Cologne [Trap10]. It uses interactive 3D virtual environments to enable the presentation of and interactive with digital cultural heritage artifacts in real-time to facilitate the communication of cultural heritage in public spaces. However, it does not consider mobile devices as platform for visualization and data access. Before exploiting the potentials of 3D mobile technology for the presentation of 3D heritage in archaeology, preservation, education, and tourism, a number of challenges have to be addresses. These include the acquisition and visualization of 3D digital assets; their semantic linking to other types of data along with the mechanisms to achieve this; the use of crowdsourcing techniques to generate content; the improvement of hardware devices and their capabilities; as well as issues on privacy and copyright protection [Echa12].

Interactive visualization of 3D virtual reconstruction on mobile devices previously has applications in virtual reality (VR) and augmented reality (AR). One application that focuses on AR is "Virtual Romans" project [Higg12] produced by De Montfort University researchers. The project aim was the exploration of computer graphics technologies to create historically accurate digital 3D models of the known Roman buildings and associated artifacts. It discusses how the 3D assets created are employed in an interactive environment including a location-based augmented reality mobile phone application. Besides presenting 3D interactive models of artifacts and buildings, the system was developed for wide-area augmented reality to visualize archaeological findings in their original locations.

Focusing on single 3D objects only, [Gill13] presents a concept that aims to provide a methodology for museums and cultural institutions for prototyping a 3D viewer within a webpage. It also describes a prototypical implementation based on WebGL and the OpenCTM file format, which enables non-skilled users to interact with the datasets and explore 3D cultural heritage objects.

3 Use Case - Colonia 3D

As an example to demonstrate our visualization approach, we chose the reconstruction of the ancient town of Cologne. To create a complete 3D model representing the ancient town of Cologne, a number of single roman structures and building elements had to be reconstructed first. The archeology experts did the reconstruction of these elements, their combination, and arrangement. For this task, known facts from previous research, results of actual publications, as well as recent finds of the local department of antiquities of the Romano-Germanic Museum Cologne were considered. Only well-studied buildings, with a scientifically evaluated shape or floor plan, were reconstructed in high detail. For all other elements only simple shapes were selected for the reconstructions to communicate the missing evidence. Additionally, a digital terrain model (DTM) of the ancient Cologne with building sites and streets was reconstructed. It was derived from a DTM of the present Cologne, whose geo-reference was adapted to the location of finds as well as to known morphological changes in the past.

The reconstruction results represent the scientific fundament and were used by the design team to create the virtual 3D models. Therefore, archaeologists delivered all suitable data, such as textual descriptions, photographs of artifacts, and highly detailed 2D computer aided design (CAD) drawings of building parts and their arrangement to the designers.

3.1 3D Model Creation

Based on this scientific evaluated material, designers created virtual 3D building models for the real-time visualization and secondary content for the presentation of additional information. The major challenge for designers is to balance the trade-off between visual quality and suitability for real-time rendering. On one hand, archaeologists demand for maximum visual quality for every detail. On the other hand, computer graphic engineers rely on low polygonal representations for fast rendering on graphics hardware, to ensure interactivity for the expected number of high-detail building models. Generally, all individual objects are constructed with the least possible amount of polygons while remaining the original shape.

After a library of 3D elements (e.g., capitals, columns, and doors) had been created, these structures were combined to complete buildings and provided with 2D texture-maps representing the respective materials. These material textures are based on color templates prepared by the archaeologists. Further, static lighting conditions are assumed to enhance the 3D impression of the models and to accelerate rendering. Therefore, the material textures are combined with light maps, which are derived from global illumination simulations.

To exchange 3D models a data format has to be selected that meet the following three criteria: (1) It has to be supported by digital content creation (DCC) tools used by the designers (Cinema4D, 3DSMax); (2) To provide content preservation, the format should be extensible, future proof, and store information lossless; (3) The format should support a minimum set of standard features (e.g., geometric transformations, color and material definitions, geometry instancing, and external references for reusing building elements. We decided to use the COLLADA exchange format. It fits all of above requirements, is based on an XML scheme, has an open specification, and is supported by a large number of major 3D hardware and software companies.

4 Image-Based Provisioning of High-Detail 3D Reconstructions

Most of the existing solutions for 3D visualization of massive 3D datasets implement the complete 3D visualization process on client side. The management and rendering of large models requires specialized graphics hardware and software since massive amounts of 3D geometry and textures have to be processed and rasterized. This currently limits the application of high detail reconstructions as means for communication of cultural heritage information to high-end stationary workstations, disallowing the application of these 3D models on the particular archaeological sites.

To overcome these limitations, our approach separates the processing and 3D rendering of massive 3D models from the 3D rendering on client side by moving the majority of the computational effort for image generation to a dedicated 3D rendering server that is implemented in a controlled hardware and software environment for highly effective, high-quality 3D rendering (Figure 2) and provides this capability through a service interface.

4.1.1 Data fusion

The original 3D input data consists of very detailed meshes together with a large amount of high-resolution textures. In order to allow the efficient generation of images from the 3D model data, a preprocessing component is used to optimize the data for 3D rendering. This process involves compactification of 3D geometry data into geometry batches that can be uploaded to and processed by GPUs efficiently. During the geometry optimization process, object IDs are assigned per modeled object in order to keep the feature data that was originally connected to objects in the 3D model accessible. This association of the original object identifier contained in the source data (e.g., a model-unique object name), and optionally available key-value pairs per object are stored in a database along with this assigned object ID. In case the original 3D model contains textures, these are reorganized as a tiled texture atlas. Each of its tiles has a unique ID, which is stored together with the geometry to which the texture is mapped. In this way, the texture tiles that are necessary for texturing the 3D model can be determined during the rendering process and uploaded efficiently into the server's video memory. Using this type of optimization and texture handling, the server system is able to handle very large texture data per model.

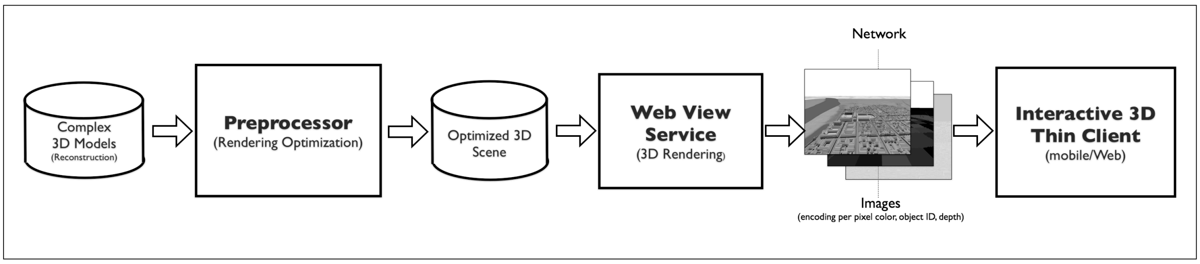

Figure 2: An overview of the distributed visualization process implemented. Since the complexity of handling and rendering massive 3D data is encapsulated on server side, the interactive client application can run on a variety of platforms with a minimal set of hardware and software requirements.

4.1.2 Service-based Rendering

The 3D rendering server provides an HTTP-based service interface for querying views on the provided 3D scene. A service request contains needs to contain all parameters necessary to define such a view, e.g. a definition of camera parameters (point of camera, its orientation, and other 3D projection parameters), scene content (i.e., which parts of the overall server-side 3D model are included in the final image), and scene styling (i.e., graphical appearance of model parts and effects to be applied to the overall image). The server exposes these functionalities through a service interface that implements the Web View Service (*WVS*) specification[1] currently in the standardization process within the Open Geospatial Consortium, an international standardization body for geospatial data and services.

The service generates so-called *image layers* each containing a specific type of data per image pixel. Examples are color images (containing a color value per pixel), depth images (containing a depth value per pixel), and object ID images (containing an object ID per pixel). This concept is well established and widely known as G-Buffers from the computer graphics domain [Sait90]. By utilizing this concept of information encoding in discrete pixels for communication with client applications, we are able to decouple the size of the data that is transferred to a client and the client-side rendering effort from the size and complexity of 3D model data on server side. No matter how complex a server-side model is, the size of the encoded image data remains nearly constant for a specific image resolution.

5 Client-side provisioning and exploitation

Since the 3D rendering service generates static images as representation of server-side 3D data for a specific camera configuration, image-based client applications usually provide a rather limited degree of interactivity (e.g., step by step browsing of 3D panoramas). Nevertheless, the interactive exploration of 3D environments is necessary for users to better understand spatial situations and relations in a 3D dataset. To support this kind of exploration, we created a client application that uses different image layers (color, depth, and object ID layers) to create a browseable, lightweight reconstruction of the server-side 3D scene.

The client application uses 3D panoramas, consisting of a cube textured with images that were generated for a specific camera position, orientation, and scene configuration (i.e., scene contents and their styling). For a fixed viewpoint, this provides a near perfect reconstruction of the server-side 3D dataset, but once the virtual camera is moved away from the center of the cube, the view is heavily distorted due to a mismatch of the projection parameters of the panorama and the projection parameters of the virtual camera.

[1] http://www.webviewservice.org

To overcome this, our image-based client application uses depth information that has been fetched from the server together with the color image data to build a partial reconstruction of the server-side scene on the client side using depth images encoded as so called depth-meshes. These meshes provide a very compact geometric representation of a 3D scene, containing relatively few triangles. They can therefore be handled and rendered also on low-end desktop computers (e.g., using WebGL[2] clients) or mobile devices (our prototype is implemented currently for the iOS platform). Since these depth meshes are generated for a specific camera viewpoint and orientation, they show more visual artifacts the further these parameters derive from the ones originally used for creation of the mesh. Nevertheless, they provide users with sufficient spatial information to be used for continuous orientation in 3D space during camera transitions. Once, navigation in the 3D scene was stopped, a new multi-layered 3D panorama is fetched and the view is updated accordingly. In this way, we create a solution that is able to display the full geometric and texture detail that is available in the model, while still being able to run in resource restricted environments such as mobile devices and web browsers.

Moreover, the server that supplies the client application with G-Buffer images offers service operations for retrieving detail information about scene objects and provides utility functions such as measuring within the scene, which is performed on the high-detail server-side 3D model and, thereby, provides a high precision as required for scientific applications.

6 Conclusions and Outlook

Using the approach presented in this paper, massive and semantically enriched 3D models, such as 3D reconstructions of archeological finds, can be utilized to make cultural heritage information accessible with a minimum of hardware and software requirement for end users. In this way, complex 3D reconstructions can also be used interactively in situ at their original geographical sites, while still providing the visual quality and access to the precise data that is necessary for the visualization to be useful for professional applications.

The highly interactive approach presented in this paper requires a dedicated rendering server to support the described client application, which restricts the number of concurrent users for a single server to several tenths of users. Here, other types of applications that are mainly based

[2] The WebGL standard provides an API for plugin-free implementation of web based 3D application that is supported by all major vendors of web browsers (see http://www.khronos.org/webgl)

on preprocessed image tiles seem promising to scale up to a large number of concurrent users, but are less flexible regarding scene contents and styling. Examples for such an application in the area of 3D city model explorations have been presented earlier [Klim14]. These applications could be adapted to fit the special needs for communicating cultural heritage information to a broader audience using state of the art rendering techniques also on mobile devices.

Literature

[Echa12] Echavarria, K. R., Kaminski, J., Arnold, D.:2012. 3D Heritage on mobile devices: scenarios and opportunities. EuroMed'12 Proceedings of the 4th international conference on Progress in Cultural Heritage Preservation; pp. 149-158

[Gill13] Gillespie, D., La Pensée, A., Cooper M. :2013. User-appropriate Viewer for High Resolution Interactive Engaments with 3D Digital Cultural Artefacts. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-5/W2

[Higg12] Higgett, N, Tatham, E, Everitt, D., Baines, E. and Saucedo, G.:2012. Virtual Romans: Virtual Reconstruction of Roman Leicester (Ratae Corieltauvorum) 210AD. VAST2012: The 13th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, pp. 37-40

[Klim14] Klimke, J. and Hagedorn, B. and Döllner, J., Scalable Multi-Platform Distribution of Spatial 3D Content, ISPRS 8th 3D GeoInfo Conference & WG II/2 Workshop 27–29 November 2013, Istanbul, Turkey, (U. Isikdag, ed.), vol. II-2/W1, ISPRS Annals,ISPRS, pp. 193-200, 2013.

[Sait90] Saito, T. and Takahashi, T.:1990. Comprehensible rendering of 3-D shapes. SIGGRAPH Computer Graphics 24(4), pp. 197–206.

[Trap10] Trapp, M. and Semmo, A. and Pokorski, R. and Herrmann, C.-D. and Döllner, J. Eichhorn, M. and Heinzelmann, M.:2010 Communication of Digital Cultural Heritage in Public Spaces by the Example of Roman Cologne. Digital Heritage, Proceedings of 3rd EuroMed Conference, LNCS, Springer-Verlag Berlin Heidelberg, pp. 262-276.