Vision Paper: The Future of Scientific Terrain Visualization

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ABSTRACT

Terrain rendering is widely used in industry and research. GIS software packages as well as navigation systems make use of terrain rendering to visualize terrain information. Recent trends in research show that scientific terrain visualization is shifting more and more to an interactive analysis tool. This allows domain specific users to perform visual analysis tasks within an interactive visual environment. Visual analysis tools are software package acting as a toolbox and providing functionality to support the work of domain specific users such as data exploration, data analysis and data presentation. Such software packages still suffer from limitations such as restricted or imprecise data and problems with large data handling. These challenges will also be at the core of research in scientific terrain visualization in the near future. In this paper we describe some open challenges for scientific terrain visualization in the acquisition, processing and rendering of terrain related geo-spatial information as well as new methods which could be used to address these challenges.

Categories and Subject Descriptors

I.3.6 [Computer Graphics]: Methodology and Techniques

Keywords

Terrain rendering, geographic information visualization, interactive rendering, large scale visualization

1. INTRODUCTION

Interactive terrain visualization is a common tool to explore and learn about the form and spatial relations of our geographical environment. The ability to visit and explore remote places without the need to visit them, as well as to view them from arbitrary angles, is a common use case for a daily user of a terrain visualization system. Furthermore there are maps, images and other information available for the users of virtual globes, navigation systems or map services. An example of an interactive terrain visualization software is shown in Fig. 1. All these applications depend directly or indirectly on efficient algorithms for interactive terrain visualization. Many of these systems are already used for 3D terrain analysis

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or geo-spatial data analysis. In the future this trend will continue to grow and scientific visualization software will allow more precise and interactive large scale geo-data analysis based on efficient terrain rendering systems.

In general we can split the data pipeline for scientific terrain visualization in three stages: data acquisition, data processing and data visualization. Despite the advances in rendering and visualization there are also ongoing projects for data acquisition and processing. The amount of available terrain and image information already exceeds the computing capabilities of desktop computers and through the exponential nature of such data sets we will have to improve infrastructure and algorithms to further progress in geographic information systems. This clearly introduces the need for collaborative tools, shared storage solutions and computing structures as we see in several open data projects. As described in Section 3.1 this trend will hold on and computing platforms and data publisher platforms will be available as on demand services in the future and will allow remote computing or remote visualization of data sets.

Another well explored aspect of map visualization systems is the shift from desktop applications to mobile applications. This allows a broader range of users for GIS systems on specific mobile platforms and more user specific applications. The improvements in graphics for mobile platforms and web browsers make it possible to provide a range of virtual globe software for those systems. However, most of these platforms are limited in terms of graphics power and therefore they are not the driving forces behind scientific algorithmic development.

The objective of this vision paper is a brief outlook to open challenges in scientific terrain visualization and to propose ideas for improving scientific terrain rendering with existing techniques from the field of computer graphics.

2. RELATED WORK

There exist a variety of works about terrain rendering algorithms in form of papers or book chapters. The works can be grouped into terrain rendering, terrain modeling and terrain analysis. In this related work section, we will first give an overview of vision papers related to terrain visualization and virtual globes as well as shortly go into recent state of the art papers in terrain visualization from a graphics point of view.

The vision paper of Christen [3] describes approaches for graphical improvements which are commonly used in the game industry and other graphics applications, such as ray casting algorithms, procedural image generation or data handling for virtual globes. How-

Figure 1: Example from our terrain rendering software using interactive continuous level-of detail and texture mapping.

ever, many of these techniques are viable only because the data sets can be well prepared and the rendering pipeline can be adjusted accordingly. This is the main difference when compared to GIS software packages, where the software is part of the data set exploration. Further requirements are precision and unknown large scale data handling, which is rather uncommon for game engines. Nevertheless there is still the objective to achieve interactive photo realistic rendering for virtual globes as well as to simulate and visualize our environment on earth more in detail.

Publications such as Dick et al. [5] show that terrain rendering can also be done using ray-casting algorithms. This approach is used in volume visualization for 3D image datasets coming for example from CT scans. In volume rendering, detailed data sets need large memory capacities in terms of data size. The article of Cozzi [4] describes a ray-casting approach for a virtual globe. However, there are still several limitations for this technique to get a broader audience and to be used in real-world systems. First, this rendering technique is computationally expensive so it is not yet viable on, for example, mobile platforms or embedded hardware. Second, the simulation of interaction between scene objects is more difficult since there are in most cases no specific mesh structures involved. Recent publications for terrain ray-casting focus on compression of terrain information [16]. This paper shows that it is possible to decode terrain information from compressed data sets in real-time on the GPU. In the follow-up paper [2], the authors describe shadow generation for terrain visualization using the same system. In Section 3.5 we will discuss the usage of hybrid visualization systems combining volume rendering techniques with mesh technology as commonly used for terrain visualization. There also exist many very efficient techniques for fast terrain rendering based on semi-regular multiresolution mesh structures as reviewed in [13] or demonstrated for example in [1].

3. TRENDS IN TERRAIN VISUALIZATION

In this chapter we describe ideas and challenges for terrain acquisition in Sections 3.1 and 3.2, terrain processing in Sections 3.3 and 3.4, terrain visualization in Sections 3.5 and 3.6, as well as an improvement to the terrain rendering pipeline in Section 3.7.

3.1 Crowd Scanning for Terrain Modeling

Point clouds can be used to improve the visual quality of available terrain information [8, 11]. Fig. 2(a) shows an outdoor laser scan which can be used to acquire detailed information about a specific location. When combined with a geographically referenced location, this data sets can be used to enhance terrain or orthographic image information to achieve precision rates of several millimeters for the scanned areas. As shown in Fig. 2(a) it is possible to acquire a 3D point cloud data sets for the area shown in Fig. 2(b). The laser scan can achieve higher resolutions per pixel as shown by a comparison of Fig. 2(b) and Fig. 2(c). In comparison to the orthographic picture with 25cm precision or the height field data with 1m precision, the point cloud scan can have down to few millimeters of precision. This means that the point cloud can reach a factor of 250 up to 1000 of higher precision compared to flight data. The top view of this example point cloud shown in Fig. 2(c) shows the limitations of this acquisition procedure. Because of missing data there is an algorithmic or human effort needed to make sure that all important details are in the scanned data set, an effort that depends mainly on the complexity of the input structure.

It is in fact possible to acquire a global scale database with scans collected, shared and provided for different purposes by different users for geographic information systems. This can be a collaborative platform similar to a crowd funding project, where everybody contributes scans of their environment to make them accessible for other users. This open database, similar to a Wikipedia for point cloud data, could be used for acquisition as well as processing these data sets, for example merging with height field or other scanned data sets.

The trend for online services will continue because such data-on-demand services are needed for a broader use of real-time interactive visualizations such as in vehicle navigation systems. The deployment chain for new data sets and interactive road information will be easier and faster. With help from an open point cloud database, a car sensor could be used to update the data in this database so that other cars can get this information almost in real-time. Furthermore, it will be possible that 3D navigation systems can access map material for every point on earth without the need

Figure 2: (a) Example point cloud showing outdoor scene in a 3D perspective view. (b) Same location marked in a orthographic photo with 25 cm resolution as used in common map software. (c) Same location as point cloud from top showing details of several millimeters.

for local data sets, something which is already available for web based map software.

3.2 Geological Information Retrieval

Another acquisition aspect, especially for scientific terrain visualization, are data sets describing the earth's surface. Computer graphics tools already allow the visualization of 3D data for geological purposes and would also allow flow visualizations and time dependent data. Still, the main challenge is the detailed acquisition of these data sets. Most of the available large scaled data sets only cover the surface of the earth, but it is rather hard to find measurements and data sets for geological insights of the earths surface coming for example from mines or other boreholes. There are some examples for mantle visualizations [15], but for more detailed visualizations more detailed data is missing. Measurements about the composition of the earths crusts, temporal geological phenomena like glaciers as in [10] or even specific snow shelf compositions for avalanche risk management would be imaginable. Such data sets can nowadays be part of a real time system improving understanding as well as predictions for risk scenarios.

3.3 Multiresolution Multi-Data Terrain Visualization

An essential challenge for terrain rendering software is the use of huge amounts of data. Level of detail algorithms exacerbate this effect. Therefore, big file repositories of geographic data exist and can be accessed over the web. On one hand, this allows software solutions the possibility to visualize remote access data. On the other hand the question is how to merge and combine visualizations of multiple repositories such that there are seamless transitions, for example, between repositories of different resolutions and different level of detail systems. This problem is a challenge on several levels. On one hand, the file hierarchies on these storage solutions of-

ten use a level of detail hierarchy allowing the applications a faster access to the repository infrastructure. On the other hand these hierarchies have to match in structure, file size, geographic projection and content related features so that it is possible to use them for a combined visualization. Terrain visualization system in the near future will have the possibility to use data sets from different storage solutions and combine image based data directly in the visualization application, so that the user can interactively change data set combinations. The use cases for such systems could be activating and deactivating a certain data layer from a specific repository but also blend certain regions of image and height field information of different layers. This can be decoupled with the terrain mesh generation to allow continuous level of detail systems as shown in Fig. 1.

3.4 Multidimensional Terrain Modeling

Terrain modeling or terrain meshing is commonly used with 2D heightfield images. There are approaches and existing techniques for modeling 3D structures such as adding artificially created object models to a scene or the visualization of digital object models (DOM) using terrain and object information provided as 2D height information. As we see from the discussion in Section 3.1, it will be necessary to provide terrain data in a 3D data structure to visualize all terrain details. The 2D height field representation can not describe 3D terrain structures as seen for example in [7]. The clear advantage will be that natural terrain structures like overhangs and man-made objects such as bridges and tunnels will be available and visible in terrain rendering systems in the same detail and naturally integrated in the data sets.

3D terrain models or man made structures are used to describe the 3D surface shape of terrain or other data. This data can be seen as sparse, because we do not care about the inner density of an object. An example for such a data set could be a highway bridge which was scanned by a local ground laser scan. Such point clouds produce final results with a precision of millimeters or higher, as discussed in Section 3.1. By now we could acquire such data and integrate it into the 2D world of terrain height fields as 2D interpretations, but one would lose most of the information by this rasterization step. One open question is how to combine such point cloud or mesh data with a common spatial data structures such as quadrees or binary trees to make a seamless grid structure for the terrain visualization possible. The objective is that the 3D visualization has a seamless transition between 2D terrain data for comparable low resolution and the high resolution point cloud. To achieve such a seamless rendering it would also be possible to use a rendering pipeline without mesh generation, for example an approach using sparse voxel octrees [14]. This technique is capable of drastically reducing the data size of a 3D grid data set and make it useful for traditional terrain visualization.

3.5 Volume Visualization in Terrain Rendering

In contrast to above, dense 3D grid information is used in volume visualization. As seen in past work [9], there is the need to use volume rendering in GIS environments. Example applications can be atmospheric phenomena such as volcano ashes, hurricanes or other weather phenomena such as pressure areas or respirable dust measurements within cities. The dense 3D volume representation requires the usage of acceleration structures like octrees for visualization purposes. Voxel based data sets are useful to explore insights of regular gridded data and identify structures or features

for example below our terrain surface. The result from a geological data set described in Section 3.2 could be a visualization showing the geological changes of a certain terrain region below the terrain surface or for example the composition of ice shields. This technique is not only useful to visualize terrain structures below ice shields such as in Antarctica, it can also be used to visualize terrain like models on extraterrestrial gas planets where the surface is not defined clearly by a rocky surface but rather by a more dense cloud of particles. Until this point the main problem is the acquisition of such data sets because for normal volume data sets, the main data sources are 3D image scanning devices, such as e.g. CT, micro-CT or MRI. Technologies like sonar systems can be used to acquire volume data as well. We can foresee that within the next years we will see more combinations of traditional terrain rendering with added features of a volume rendering system.

3.6 Uncertainty Visualization

The technical side of terrain rendering has advanced quite a lot and several terrain analysis functions arise from that. Recent publications such as [6] show that terrain rendering developed from a pure visualization problem to an interactive instrument as part of a workflow process to explore as well as interactively present data and results. An important aspect is the trustworthiness of the data. With more precision of the acquired data set there will be more use cases where the precision really matters for important long term decisions. An example of this are airborne systems where the development is restrictive due to the uncertainty of the data precision. For such cases, a visual feedback in form of colorization (or other forms of visualization) are already useful for today's terrain analysis. Finding a height field point from laser scan data includes already an error bound, which arises as an error of the measuring device or as an error by the triangulation algorithm done while determining the point's position. This uncertainty can be used to improve the visual quality of a terrain visualization for the domain expert or the domain users. They are then able to identify regions with precise measurements or areas with a high amount of error or uncertain data. A future real world scenario can be a system to build a house. It will be possible to show the uncertainty of disaster forecasts like avalanches or mudflow within the region of the building ground based on available simulation data. The system will also be able to show the building ground region where the ground stability measurements are unclear.

3.7 Deferred Rendering Pipelines

Several programs allow the creation of physically plausible terrains with a very good rendering quality for individually rendered images. It is possible to take over rendering methods for interactive real-time rendering, but not all methods are applicable to interactive frame rates. In computer graphics there is a shift in graphics engine technology replacing common forward rendering engines with deferred rendering engines. A deferred rendering engine as described by Shishkovtsov [12] enables more advanced rendering methods. Such a graphics pipeline is used for special effects for instance shading effects, blurring, highlighting, depth of field or user specific processing tasks like custom shape colorization. The advantage of a deferred rendering pipeline is the avoidance of multiple geometry passes for each of these effects, if they can be done in screen space. Furthermore, specific GIS related image effects like old style maps or hachures can be implemented algorithmically.

4. CONCLUSIONS

In this short paper we presented several new ideas and challenges for future terrain visualization systems. We assume that the mea-

surement and acquisition technologies will change again in the future, and therefore, we will also need systems capable of visualizing such data sets. Since terrain visualization is not limited to the earth, recent discoveries in space science reveal the need to use terrain visualization for extraterrestrial planets and moons to explore and analyze terrain surface data which we can obtain from satellites but not visit in person.

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