Scientific Visualization for Space Science Data Analysis in Collaborative Virtual Environments

Wito Engelke [1] * Arturo S. Garcia [2] † Robin Wolff [1] Christian Bar [3] ‡ Terrence Fernando [2] David J. Roberts [2] Andreas Gerndt [1]

[1] German Aerospace Center (DLR), Simulation and Software Technology [2] The University of Salford, UK [3] Thales Alenia Space, Italy

1 Introduction

The European research project CROSS DRIVE (Collaborative Rover Operations and Planetary Science Analysis System based on Distributed Remote and Interactive Virtual Environments) aims at developing an innovative collaborative workspace infrastructure enabling remote scientific and engineering experts to collectively analyze and interpret combined datasets using shared simulation tools [1]. The three year project started in January 2014 and unites best European expertise in the fields of planetary research and Mars science, Virtual Reality (VR), atmospheric science and research as well as rover mission planning. The research and development focus on three use case studies: landing site characterization, atmospheric science and rover target selection. The requirement analysis and evaluation is driven by experiences from past missions and with close view on the ESA ExoMars 2016 TGO and 2018 rover mission.

2 Motivation

Space exploration missions have produced vast amounts of data that are of potentially immense value for research but also for planning and during the operation of future missions. Past Mars missions, for example, have delivered data ranging from full coverage digital terrain model (DTM) over high resolution local coverage DTM and imagery data to subsurface radar and time-dependent atmospheric data. Besides the data provided by scientific instruments, a very large amount of simulated data exists. Such a rate of valuable data acquisition requires that scientists, researchers and engineers coordinate their storage, processing and relevant tools to enable efficient data analysis. The majority of this data, however, as well as the corresponding analysis tools are fragmented over different institutions and research facilities. A combination and wider availability would unlock the full potential for scientific analysis and future mission planning. Scientists and engineers would benefit from interactive exploration and powerful data analysis tools. With this at hand the growing amount of data could be analyzed faster and deeper understanding could be gained. Furthermore, combining science data fields with different spatial and temporal resolutions from different missions allows to gain insight into the complex inter-dependencies of diverse science domains. Hence, the goal of the CROSS DRIVE project is to create the foundations for interactive data exploration by moving the analysis and discussion process (e.g., for future mission planning) to a collaborative and immersive workspace. The combination of real-time scientific visualization, Virtual Reality and the collaborative environment creates a unique platform for space scientists as well as engineers and facilitates the exploitation of space science data.

*e-mail:{Wito.Engelke,Robin.Wolff,Andreas.Gerndt}@dlr.de
†e-mail:{A.S.GarciaJimenez,D.J.Roberts,T.Fernando}@salford.ac.uk
‡e-mail:Christian.Bar@external.thalesaleniaspace.com

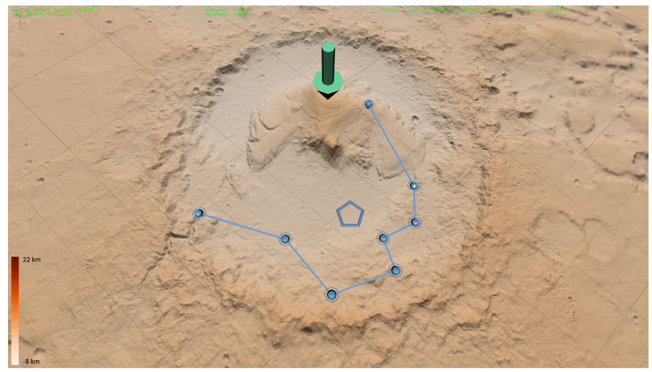

Figure 1: Direct visualization of DTM data on a yellow to red color scale and interactive GIS tools (Gale crater on Mars)

3 Current State

At the current state of the project, different geo-referenced planetary data sources have been combined and interactive geographic information systems (GIS) tools have been developed. Figure 1 shows a direct visualization of the DTM data, as shaded relief, of the crater Gale on Mars (5.4 S, 137.8 E) together with a small subset of the available GIS tools [2]. The evaluation of the use case of landing site characterization will focus on this specific area. The terrain visualization and the GIS tools are designed for the core collaborative workspace connecting remote immersive virtual environments to a shared space. This means all relevant aspects of the terrain visualization (e.g., datasets, applied shaders, terrain exaggeration) as well as properties of the interactive GIS tools (e.g., position, color) are synchronized between the connected application instances. The communication is handled via a dedicated network layer which maintains the consistent state of all data shared between participants. Update messages are passed within a server-client architecture over secure connections. The application can currently be configured to be employed on hardware ranging from laptops to large scale VR environments. The main target platform will be a immersive virtual environment, though. Therefore, the design of interaction methods and tools have to subordinate to this architecture.

4 Visualization

The visualization of terrain data on a planetary scale is a challenging task. The system has to handle very large datasets with high resolution. Typically, datasets range from hundreds of gigabytes to several terabytes. In addition to that, the application has to guarantee shared data synchronization and render additional geometry (e.g., GIS tools). These different tasks have to be performed at high frame-rates to allow interactive stereoscopic rendering on VR platforms, ideally with a minimum update rate of 30 Hz per eye.

For the terrain visualization, we use the level of detail (LOD) approach presented by Westerteiger et. al. [3] to achieve high render-

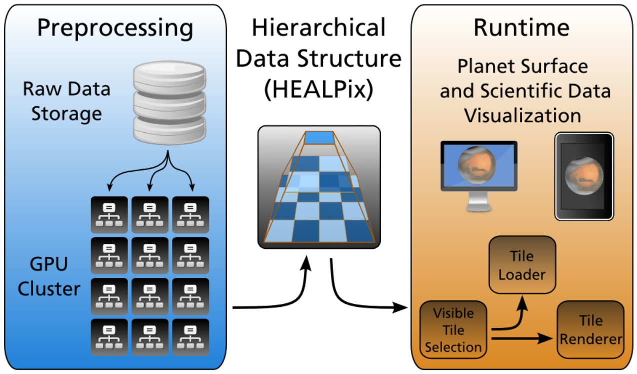

Figure 2: Data Processing Pipeline: Raw data is processed and each data set is stored as level-of-detail (LOD) friendly database file. During visualization these files are partially loaded. The LOD structure is constantly updated and new tiles are loaded from the files on demand.

ing performance with maximum detail. It uses a quad-tree structure based on the HEALPix tessellation of a sphere [4, 5]. The properties of this tessellation have the advantage of being self similar and area preserving when mapping from texture space to object space. This allows us, firstly, to easily organize the original raster data into tiles of a quad-tree and, secondly, avoids distortion artifacts at the poles. The renderer evaluates the presented detail by first projecting the bounding box of the loaded terrain tiles with their current LOD onto the screen. Then, the covered screen area is compared with respect to the tile resolution. If the projected area, specifically the amount of covered pixels, on the screen is larger then the amount of data samples, then a higher resolution level is loaded, if available. The threshold of the ratio between covered screen area and tile resolution can be adapted to the target hardware at run-time. In Figure 1, DTM data is directly visualized by mapping surface height to a color scale (i.e. yellow to red) and applying a local shading method. Additionally, individual HEALpix patches are made visible by thin gray lines.

If the renderer requests a higher resolution LOD, the necessary data is uploaded from main memory to the GPU. If a requested LOD of a specific tile is not yet available in main memory, it is loaded in a background thread from disk or network. For minimizing data loading overhead, we preprocess geo-referenced data into a optimized, single, LOD-friendly database file. Figure 2 illustrates the process of database generation.

In the context of interactive visualization, we limit the time-slot for processing one frame to 16 ms. This includes all LOD updates and the loading of additional data. If available we present at least one data sample for each pixel on the output device(s). LOD updates can be delayed to subsequent frames if the current frame budget is exceeded.

The application can handle several database files simultaneously, enabling the scientist to switch between different datasets for analysis and comparison. Furthermore, the scientist can apply different shader programs to adapt the visual representation of the data to the specific needs of the analysis task. In addition to the terrain visualization as integral building block of the application, the visualization system provides a number of interactive GIS tools. A small subset of these tools (rover path planning tool and landmark annotation) are shown in Figure 1. Such items are less challenging for the visualization system, since they are represented by simple geometry and shapes. However, they are an important asset for the scientists in the analysis sessions.

5 Virtual Reality

Immersive virtual environments can create the illusion of being "teleported" to the planet one is exploring and, for example, give the scientist the possibility to travel along the terrain to explore various terrain features. Furthermore, atmospheric and subsurface datasets can be analyzed in the dimensions of time and space. Providing intuitive interaction techniques for the GIS tools enables a virtual field trip to distant planets. The application development of the presented visualization system is supported by the ViSTA VR-toolkit [6]. It is a C++ framework for the development of VR applications and provides platform abstraction, clustering, access to a scenegraph, and interfaces to a wide range of interaction devices.

6 Conclusion and Future Work

In this poster we presented how visualization, in particular terrain visualization, is used as one of the most important building blocks in the CROSS DRIVE project. The combination of visualization, Virtual Reality, collaborative workspaces, and scalability with direct focus on specific use cases in the space domain and planetary research is unique. We presented the current state of the project and addressed the important aspects. In the remaining time of the project we will integrate real-time video avatars as virtual representation of scientists and further extend and improve our system. We will target additional scientific data (e.g., subsurface and time-dependent atmospheric data) as well as virtual rover models which are controlled by external simulations. Besides that, we will improve the visual quality by adding real-time shadow generation and atmospheric scattering.

7 Partners

The joint research and development partners of the project are:

- German Aerospace Center (DLR), Germany
- The University of Salford, United Kingdom
- Advanced Logistics Technology Engineering Center, Italy
- Thales Alenia Space Italia, Italy
- Istituto Nazionale di Astrofisica, Italy
- Institut dAeronomie Spatiale de Belgique, Belgium
- National University Corporation Tohoku University, Japan

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