Web-based Visualization Platform for Geospatial Data

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Abstract: This paper describes a new platform for geospatial data analysis. The main purpose is to explore new ways to visualize and interact with multidimensional satellite data and computed models from various Earth Observation missions. The new V-MANIP platform facilitates a multidimensional exploring approach that allows to view the same dataset in multiple viewers at the same time to efficiently find and explore interesting features within the shown data. The platform provides visual analytics capabilities including viewers for displaying 2D or 3D data representations, as well as for volumetric input data. Via a simple configuration file the system can be configured for different stakeholder use cases, by defining desired data sources and available viewer modules. The system architecture, which will be discussed in this paper in detail, uses Open Geospatial Consortium web service interfaces to allow an easy integration of new visualization modules. The implemented software is based on open source libraries and uses modern web technologies to provide a platform-independent, plugin-free user experience.

1 INTRODUCTION

In the earth observation (EO) context a variety of sensing devices is used to collect various types of information in different formats. With the continuous evolution of technology the resolution and thus the amount of acquired data is increasing constantly. Because of this overwhelming data amount and heterogeneous data sources it is hard, e.g., to find interesting meteorological phenomenons or data correlations between the heterogeneous datasets, especially if the phenomenon or data correlation is not known beforehand and cannot be searched for in an automatic way. Tools providing efficient workflow to search and explore within heterogeneous earth observation data are therefore key for selecting the interesting portions of the input data for further processing, and to skip portions containing non-useful data. Secondly, comparing and analyzing data from different data sources plays an important role in the field, e.g. when comparing a computed scientific weather model output with the actual satellite data to assess its accuracy.

In this paper we describe a web-based visualization platform focusing on a ”Browse & Discover” workflow to search through huge data repositories from Earth Observation (EO) missions (e.g., imagery and volume data from a satellite sensors), as well as on a ”Compare & Analyse” workflow to assess data from multiple EO sources. The development of the platform and a reference prototype is embedded into the research project V-MANIP (Multidimensional Visualization and Manipulation of Data). In this paper we focus on the ”Visualization” subsystems of the project. V-MANIP is used by scientific users such as environmental analysts or meteorological office personnel which require access to EO data to support their research or decision support process. In the project, requirements were collected to base the system architecture on. These requirements where defined together with the meteorological science community. Use cases were also defined to validate the platform. A description of the use cases can be found in Section 3, results of the validation are part of Section 5. A demo of the V-MANIP prototype can be found at `http://demo.v-manip.eox.at`.

The described platform is conceptually divided into a frontend layer running in the web browser as a web application, and a backend server layer. The frontend provides the general user interface, as well as a set of viewer components for visualizing EO data. The backend server is responsible for preprocessing the raw input data from different data sources into formats which can be visualized at interactive frame rates in the web application. The communication between the two layers and the internal components within the layers are handled through Open Geospatial Consortium (OGC) standard and proposed standard protocols.

The web application provides a user with a set of default graphical widgets to perform operations common for the collected use cases. Figure 1 shows the graphical user interface of the application. A "Layers Selection Widget" allows to select which data sources are displayed. A "Timeline Widget" gives the user visual information where on the timeline data exists for the selected layers. It also allows the user to select a time of interest (TOI) to show data available in the selected timespan. To select an area of interest (AOI) the "Toolbar Widget" provides different selection tools, including point, line, box and polygon selections. One main goal of the V-MANIP platform is to provide the user with the possibility to visualize one or multiple data sources simultaneously in different viewers. For that reason a "Split View" feature allows to divide the screen into a multi-window setup. Each of the windows can have it's own viewer assigned. The viewers are synchronized to show the same spatial area and they react on events like selecting different layers, AOI or TOI.

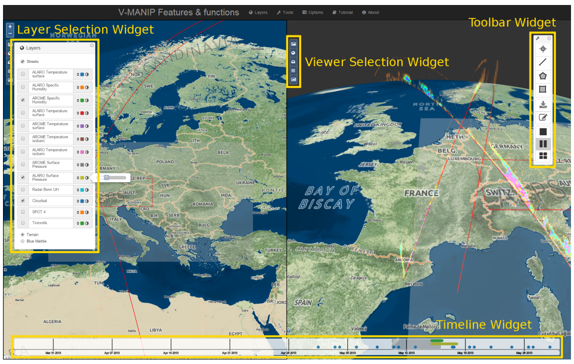

Figure 1: Web application GUI with default widgets: Layer Selection, Viewer Selection, Timeline and Toolbar.

Four viewers are provided with the system: The 2D Map Viewer, the Virtual Globe Viewer (VGV), the Rectangular Box Viewer (RBV) and the 2D Visual Analytics Viewer. The 2D Map Viewer is not described in detail in this paper. It provides the visualization of two-dimensional map imagery and various overlay possibilities for displaying multiple data sources together. The Virtual Globe Viewer (VGV) is a 3D globe for displaying maps, overlays and 3D geometry. The Rectangular Box Viewer (RBV) displays volumetric data using image stacks. The 2D Visual Analytics Viewer provides analytics information for a data selection.

2 RELATED WORK

Visualization of abstract data such as sensor values in the geospatial context has become more and more important in recent years. Dykes (Dykes et al., 2005) provide a survey of existing systems and future trends of geo-visualization. As one example of combining geographical and multivariate visualizations, Butkiewicz et al. draw iconic representations (called probes) of multivariate views as detail information for certain spots of a geographical context (Butkiewicz et al., 2008). As another example, Brooks et al. proposed a hybrid 2D/3D approach by showing multiple information layers on top of a base terrain (Brooks and Whalley, 2008). Zhang et al. presented a visual analytics framework to analyse climate data. They provide linked views of parallel coordinates with a Google Earth plug-in, where 2D diagrams are embedded (Zhang et al., 2013).

In many cases, time also plays an important role when analyzing geographical data. Andrienko et al. have proposed multiple approaches for visualizing spatiotemporal patterns, including methods based on self-organizing maps (Andrienko et al., 2010). Kapler et al. integrate time in 2D and 2.5D terrain visualizations as an orthogonal axis (Kapler and Wright, 2004). In order to display more general data, Tominski (Tominski et al., 2005) proposed several 3D icons for embedding temporal multivariate data on top of maps. In all these cases, spatial information is provided by more or less standard maps. In contrast, we envision a tight combination of a 3D globe with linked interactive views providing analytic capabilities.

There are some other web-based globe viewer systems. One of them is Cesium, which is a WebGL virtual globe with an integrated map engine. It allows to watch orbits of satellites or the ISS in real-time. Cesium does not support linked split views and it is not its aim to explore Earth observation data.

OpenWebGlobe is an open source virtual globe SDK implemented on base of HTML5, WebGL and Javascript. The project was initiated by the Institute of Geomatics Engineering (IVGI) of the FHNW University of Applied Sciences and Arts Northwestern Switzerland (IVGI) and released as open source in

April 2011. Since then the functionality is being extended continuously. The focus lies on processing and rendering of massive 3D geospatial environments.

3 COVERED USE CASES

The V-MANIP project was driven by the input of the research community to build a platform that helps scientists in their daily work. For that reason real-life use cases were defined that served as validation scenarios for the developed software. The following list shows defined use cases, each use case shows the configured web application for the scenario in a screenshot to give the reader an impression of the flexibility and configurability of the system.

UC1: 3D validation of numerical weather prediction model output with satellite data to verify the capabilities of the system to visualize, analyze and compare multi-dimensional data coming from numerical weather prediction models and satellite system (see Figure 2).

UC2: Data quality control of a meteorological network with satellite data to test the ability of the system for monitoring a meteorological network and identifying suspicious ground measurements with reference to satellite and numerical weather prediction model data (see Figure 3).

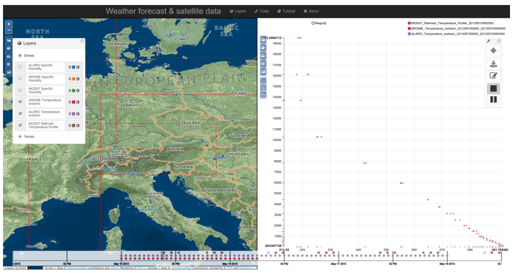

Figure 2: [UC1] 3D validation of numerical weather prediction model output with satellite data.

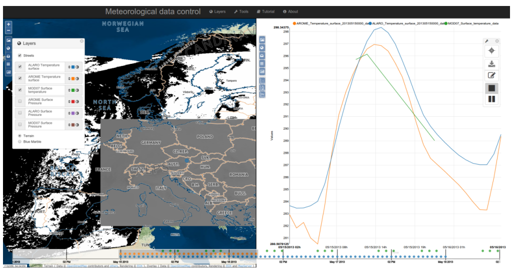

Figure 3: [UC2] Data quality control of a meteorological network with satellite data.

UC3: Multi-dimensional cloud data analysis aims at verifying the capabilities of the system to visualize and analyze two-dimensional and three dimensional data coming from space-borne platforms and on ground measuring systems (weather radar). The main scope is to verify the possibility to see combined satellite cloud structure and precipitation data combined with ground weather radar observations (see Figure 4).

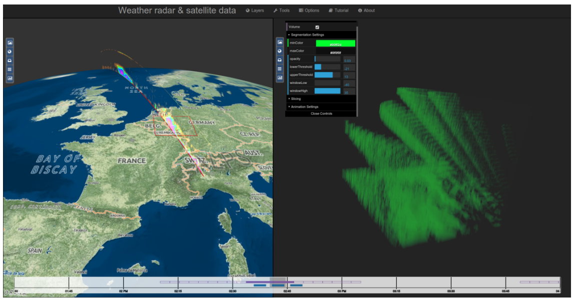

Figure 4: [UC3] Multi-dimensional cloud data analysis.

4 SYSTEM ARCHITECTURE

The V-MANIP sofware platform allows the registration and visualization of two and three dimensional EO data. The registration and access control for the data through the Data Preparation Subsystem and the Security Subsystem are not part of this description. This paper is focused on the 3D Client-Server Subsystem and the Visual Analytics Client-Server Subsystem. Figure 5 shows the system architecture as a whole, including all subsystems. Each subsystem consists of one or multiple components. The communication between the subsystems and components is handled via standardized or standard candidate interfaces from the Open Geospatial Consortium (OGC), namely the Web Map Service (WMS) , Web Map Tile Service (WMS) , Web 3D Service (W3DS) and the Web Processing Service (WPS) , which are linked in the references.

4.1 3D CLIENT-SERVER SUBSYSTEM

The 3D Client-Server subsystem (3DCS) is divided into a frontend web client and a backend server system. The web client is running within a Javascript capable web browser with no additional plugins installed. It provides two viewer components: the Virtual Globe Viewer (VGV) and the Rectangular Box Viewer (RBV). The two viewers are responsible for

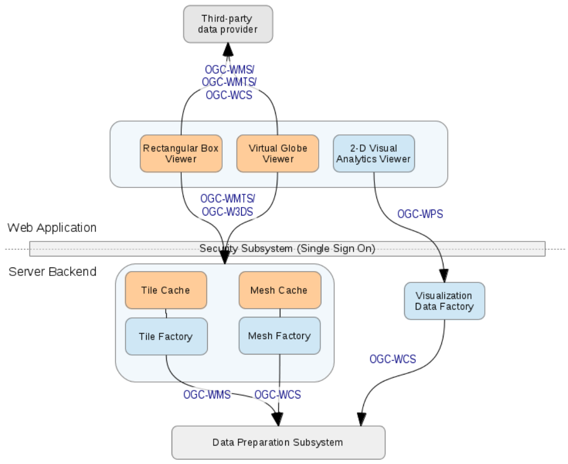

Figure 5: System architecture including all subsystems and the interfaces between the subsystems' components. This paper describes a) the 3D Client-Server Subsystem including the components colored in orange and b) the Visual Analytics Client-Server Subsystem including the components colored in blue.

visualizing the EO datasets. For an interactive experience when browsing and displaying EO data it has to be streamed to the VGV and RBV viewer efficiently. The architecture foresees that CPU intense preprocessing of the EO data is performed on the backend server and the result is stored in a caching system. This allows low-latency requests for the data from the viewers. Two caches are implemented, one for 2D images (Tile Cache) and one for 3D mesh data (Mesh Cache). The preprocessing itself is done by the Factory system, which is described in Section 4.2.3 and 4.2.4. Figure 5 shows the architecture of the 3DCS with the client and server components.

4.1.1 VIRTUAL GLOBE VIEWER

The web-based Virtual Globe Viewer component is a globe application that allows a user to navigate on the globe and to display 2D imagery data as layers, as well as 3D geometry in a spatial context. The selection tools from the Toolbox widgets allow to select spatial areas to interact with the data, e.g. to examine it in the 2D Visual Analytics Viewer (see 4.2.1).

The VGV is based on the open source library GlobWeb (GlobWeb, 2014). This library was extended to visualize "Vertical Curtains", meaning that a mesh comparable to a vertical plane is displayed on the globe following the satellite track that captured the sensor data with a certain inclination. The preprocessed sensor data is mapped as a texture onto the vertical mesh, forming a vertical curtain. The generation of the mesh (vertex positions, vertex normal and texture coordinates) for a vertical curtain is done in the Mesh Factory (see 4.2.4); the result is stored in the Mesh Cache (see 4.1.4). Via the W3DS interface the cached vertical mesh data is transferred to the Virtual Globe Viewer via the OpenGL Transmission Format (glTF, 2014), a compact, final stage transmission format to enable rapid delivery and loading of 3D content optimized for WebGL. The glTF format also contains web references to the textures mapped onto the mesh. The referenced image data is fetched by the VGV after loading the glTF data via the WMTS interface of the Tile Cache (see 4.1.3). Figure 4 shows a vertical curtain example on the left.

4.1.2 RECTANGULAR BOX VIEWER

The Rectangular Box Viewer (RBV) is a component for visualizing data layers containing volume data, e.g., radar data from a satellite. In selecting an AOI and TOI via the application widgets the corresponding volume data is loaded into the viewer for an interactive examination.

In the V-MANIP datasets volumetric-data is orthogonal to the view direction of the satellite. In the data preparation module this data is added to the system via multi-frame TIFF files, forming an image stack with one defined axis orthogonal to the satellite view direction. For the ease of description we consider the case of a zero degree inclination of the images (the second type in V-MANIP would be 45° inclination), which means that the images are aligned orthogonal to the vertical (with respect to the globe) axis. The RBV will request an area of an images stack via W3DS (where the images are contained in a single container format), resulting in a certain number of images within the client. Image stacks for all axes are prepared on the client side. A second visualization option is to render the images in the stack blended over each other (depending on the view direction). The base software library for the RBV is the XTK library (The X Toolkit (XTK), 2014).

4.1.3 TILE CACHE

The Tile Cache component provides a cache of overlay images from V-MANIP layers as well as textures to be applied to vertical curtains. The benefits of using a cache is that the on-the-fly production of the tiles may be too time-demanding for a responsive user experience. A pre-seeded cache simply has to return the requested tiles with little or no overhead regarding the processing time for data creation. The data stored in the cache is requested from the Mesh Factory and stored in an WMTS compatible database structure. The cached data can be requested by the web application's viewer modules via the WMTS protocol.

4.1.4 MESH CACHE

The Mesh Cache is located in the server backend and stores all mesh information necessary to display vertical curtains. The stored data consists of vertex position, vertex normals and texture coordinates to map pre-processed texture images - which contain the actual EO information - onto the mesh. When the web application requests a specific vertical curtain tile via the W3DS interface the cache checks if the tile is already created. If not, the data is requested from the Mesh Factory component, which creates the mesh information for the vertical curtain. The main purpose of this cache is to enable fast data transmission to a client. To ensure a reasonable transmission time to a request it is necessary to keep the size of the transmitted data at a minimum. This is taken care of in using the glTF format as output format of the Mesh Factory. glTF includes mesh compression algorithms for minimizing the transmission size.

4.2 VISUAL ANALYTICS CLIENT-SERVER SUBSYSTEM

The Visual Analytics Subsystem consists of components to enable an interactive, visual analysis of Earth observation data. It applies methods of information visualization for in-depth visual exploration of complex data and its relations. These components are described in the following sub-sections.

4.2.1 VISUAL ANALYTICS VIEWER

The Visual Analytics Viewer provides different information visualization methods for interactive visual analysis of Earth observation data. This allows detailed investigation of selected data sets. Complex data sets and their relations are intuitively comprehensible. It makes outliers and clusters easily perceptible. This subsystem is based on the Javascript library Data Driven Documents (D3) (Bostock, 2014). A set of different interactive views has been selected based on use cases, which are a box plot for statistical analysis, a scatter plot showing data distribution, parallel coordinates for relations of multivariate values and streamlines for direct visual comparison of time series. It is embedded in a multi-view web client and thus preservers the geo-spatial context.

4.2.2 VISUALIZATION DATA FACTORY

The Visualization Data Factory is a component located on the server backend and services various processes through WPS. Requesting the execution of a specific process with the expected parameters will return a result that can then be visualized by the 2D Analytics Viewer component. The Visualization Data Factory can access registered data directly as well as execute various processes which return processing results.

4.2.3 TILE FACTORY

The Tile Factory generates data requested by the Tile Cache (see 4.1.4) and serves it through WMS. Volumetric data is represented by a stack of GeoTIFF layers (Sazid Mahammad and Ramakrishnan, 2014). Each layer represents a volumetric slice parallel to the ground. This stack is converted by the Tile Factory in an volumetric representation encoded in the NIfTI-1 data format (National Institutes of Health, 2014). The Tile Cache requests volumetric data within the bounds of a single tile from the Tile Factory, which crops and merges the GeoTiff layers accordingly.

4.2.4 MESH FACTORY

The Mesh Factory generates the 3D mesh and texture data needed by the Virtual Globe Viewer, which requests it via the Mesh Cache. The data is provided to the Mesh Cache through the GetScene request, as specified in the W3DS standard.

The Mesh Factory requests vertical curtain data information from a database on the file system, which was populated by the Data Preparation Subsystem. This data is delivered as XML encoded sample points along the satellite footprint path and height values, and GeoTIFF (Sazid Mahammad and Ramakrishnan, 2014) images containing the actual measurements on the vertical grid specified by these sample points. These samples occur in continuous strips along the satellites path on the ground. The Mesh factory has to crop and merge them to the bounds of the tile requested by the Mesh Cache. Special care has to be taken to cover all edge cases that occur when clipping geometric data on a spherical topology: wraparound of coordinates over the 180°meridian, singularities on the poles and paths coinciding with tile borders. The processed geometry representing the vertical satellite measurements over time result in a dense geometric mesh. To reduce the rendering load for the viewer, especially when many curtains are visible, the geometry can be requested in several levels of detail. Both mesh and textures are reduced, resulting in approximately the same amount of data for all tile sizes. The mesh is delivered as compressed binary data in the glTF format. The format is currently in the OGC's standard candidate phase and will in our opinion future-proof our interface.

5 CONCLUSION

The target science communities were included in a continuous evaluation process during the project. They expressed a clear interest in the results an even the desire to incorporate V-MANIP into some of their platforms. Interactive tutorials for every use case allowed new users to become easily acquainted with the software.

Some of the functionalities considered and reported as highlights by the validation group members are:

- Web application approach: No need for installing or updating software on their local machine.
- Performance of the system: Speed of data access and data manipulation.
- Time slider: Allows easy interpretation of where and when data is available.
- Several illustration facilities: 2D views on map/virtual globe, 3D views both in space (x,y,z) and space/time (x,y,t) and analytical tools to display time series at selected points.
- The visualization of temporal and spatial availability of different data sources and the possibility to combine different data sources in one application which is essential for data viewing and data mining with regard to big data.

Future work topics collected from the validation group were:

- Additional information of the visualized data, such as recording mission or sensor type and its processing pipeline should be displayed, as well as what algorithms were applied or which entities did process the data.
- Upload of local data: Provide an interface to allow direct upload of local data (e.g. data owned by an institution) to be integrated into the system for visualization.

In collaboration with science communities new visualizations and algorithms can be defined extending the functionality of the open-source platform.

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REFERENCES

Andrienko, G., Andrienko, N., Bremm, S., Schreck, T., von Landesberger, T., Bak, P., and Keim, D. (2010). Space-in-time and Time-in-space Self-organizing Maps for Exploring Spatiotemporal Patterns. In *Proceedings of the 12th Eurographics / IEEE - VGTC Conference on Visualization*, EuroVis'10, pages 913–922, Aire-la-Ville, Switzerland, Switzerland. Eurographics Association.

Bostock, M. (2014). Data-Driven Documents (D3). *http://d3js.org/*.

Brooks, S. and Whalley, J. L. (2008). Multilayer hybrid visualizations to support 3D GIS. *Computers, Environment and Urban Systems*, pages 278–292.

Butkiewicz, T., Dou, W., Wartell, Z., Ribarsky, W., and Chang, R. (2008). Multi-Focused Geospatial Analysis Using Probes. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1165–1172.

Dykes, J., Fabrikant, S., and Wood, J. (2005). Preface. In Kraak, J. D. M. M.-J., editor, *Exploring Geovisualization*, International Cartographic Association, pages ix – xii. Elsevier, Oxford.

GlobWeb (2014). Virtual Globe with WebGL. *https://github.com/TPZF/GlobWeb*.

glTF (2014). Runtime asset format for WebGL, OpenGL ES, and OpenGL. *https://www.khronos.org/gltf*.

Kapler, T. and Wright, W. (2004). GeoTime Information Visualization. In *Proceedings of the IEEE Symposium on Information Visualization*, INFOVIS '04, pages 25–32, Washington, DC, USA. IEEE Computer Society.

National Institutes of Health (2014). Nifti - neuroimaging informatics technology initiative.

Sazid Mahammad, S. and Ramakrishnan, R. (2014). GeoTIFF - A standard image file format for GIS applications. *http://www.gisdevelopment.net/technology/ip/mi03117pf.htm*.

Schilling, A. and Kolbe, T. H. (2010). Draft for OpenGIS Web 3D Service Implementation Standard. *http://www.w3ds.org/doku.php*.

The X Toolkit (XTK) (2014). *https://github.com/xtk/X*.

Tominski, C., Schulze-Wollgast, P., and Schumann, H. (2005). 3D Information Visualization for Time Dependent Data on Maps. In *Proceedings of the Ninth International Conference on Information Visualisation*, IV '05, pages 175–181, Washington, DC, USA. IEEE Computer Society.

Web Map Service (WMS) (2014). *http://www.opengeospatial.org/standards/wms*.

Web Map Tile Service (WMTS) (2014). *http://www.opengeospatial.org/standards/wmts*.

Web Processing Service (WPS) (2014). *http://www.opengeospatial.org/standards/wps*.

Zhang, Z., Tong, X., McDonnell, K., Zelenyuk, A., Imre, D., and Mueller, K. (2013). An interactive visual analytics framework for multi-field data in a geo-spatial context. *Tsinghua Science and Technology on Visualization and Computer Graphics*, 18(2):111–124.