Mixed 2D/3D visualization of a large scale groundwater study in a virtual reality centre

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Abstract As part of a project which deals with a large-scale groundwater study aimed at simulating the available groundwater resources in the Upper Mega Aquifer system in the eastern part of Saudi Arabia, an interactive visualization has been created in order to show the simulation results, together with the original borehole data from which the input model was constructed and placed within the context of the geological surroundings in an easily understandable way. The 3D visualization can be run in a stereoscopic visualization centre and is augmented by additional 2D visualizations that help users to orient themselves within the virtual scenery and which also show additional information upon selection of corresponding objects in the 3D scene.

Key words 2D; 3D; groundwater; visualization; virtual reality

INTRODUCTION

Visualizing large scale regional studies that involve complex geometries, multiple parameters and time-dependent processes is often a challenge. This is especially true if the visualization of diverse results needs to be explained intuitively to the public, politicians or stakeholders for planning or decision-making purposes. The viewers can quickly lose their orientation when they move into the 3D scene and it becomes difficult to focus on specific simulation results within a given context. For this reason the Helmholtz Centre for Environmental Research (UFZ) uses a projection-based visualization centre (TESSIN-VISLab) that shows the 3D scenery on a large rear screen using stereoscopic rendering. This can be augmented with 2D visualizations, such as maps and linked views, using two additional side screens. The combined 2D/3D representation allows the use of synoptic views of complicated data that are easy to navigate and comprehend (Zehner, 2010).

The visualization methodology is demonstrated using a large-scale regional groundwater study in Saudi Arabia in the context of the IWAS project (Kalbus *et al.*, 2010). The overall target is to provide a precise quantification of the groundwater resources available, including groundwater recharge, and to use numerical modelling to assess potential exploitation scenarios. For the numerical simulation the finite element software OpenGeoSys (OGS, Wang *et al.*, 2009) has been used. We have set up the visualization of the groundwater simulation showing the time-dependent hydraulic head using isosurfaces, and the resulting groundwater flow using streamlines, together with borehole locations and the structural interpretation of the geology. Further, meteorological data such as precipitation events can be shown. To generate this visualization, it was necessary to implement or extend several software modules in order to establish the interfaces required between the simulation software OpenGeoSys and the software needed for the visualization centre.

This contribution will first outline the technology of the visualization centre and how it is run in mixed 2D/3D mode by specialized software with additionally implemented plug-ins. It will then explain the overall workflow for the preparation of the data that is necessary and which involves our own pre- and post-processing toolkit for the simulation software OpenGeoSys (Kalbacher *et al.*, 2011; Rink *et al.*, 2011).

VISUALIZATION METHODOLOGY

Studies in geosciences, such as the one described here, often involve many different data that are distributed in space. While the overall content to be shown is inherently 3D, many of the data to be investigated are better shown as 2D graphics. Examples include stratigraphic profiles along boreholes or maps. Further, it is usually not possible to show all the information simultaneously, so that an interactive system is needed that allows the users to select the information they currently need. For problems that can be projected onto 2D maps this is, for example, done by Geographic Information Systems. If the problem is inherently 3D and contains complicated structures, a Virtual Reality system that allows for direct interaction in 3D space might be more suitable.

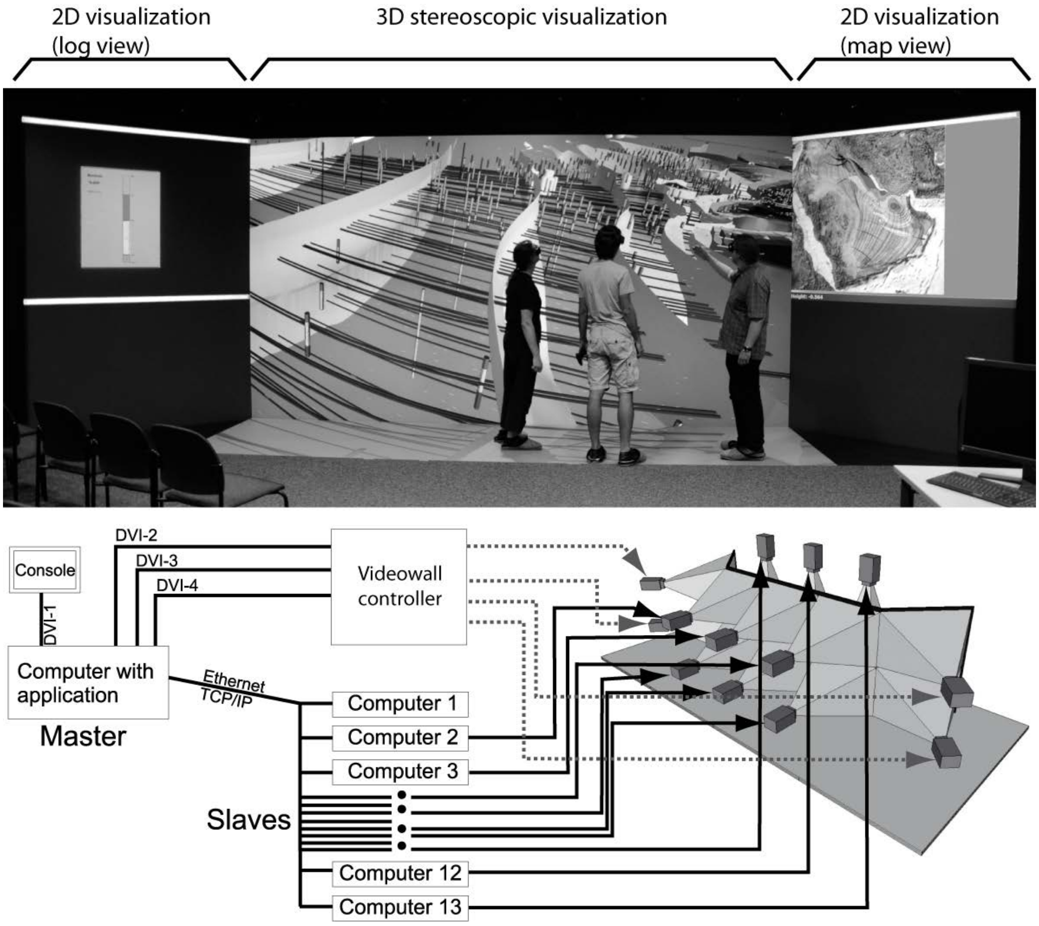

Fig. 1 The visualization centre at the Helmholtz Centre for Environmental Research – UFZ. Top: Three people examining the dataset; the right screen shows a map of Saudi Arabia to help them orient themselves in the virtual scene. On the left, additional data for a selected borehole are shown. Bottom schematic view of how the centre is run using a computer cluster to generate the images for the projectors on the floor and on the rear screen (solid lines from the computers to the projectors), while the images for the projectors on the side screens are generated using a video wall controller (dotted lines).

In order to meet the aforementioned requirements, the UFZ's Visualization Centre has been designed in such a way that it supports the combined visualization of 3D content in a high resolution head-tracked stereoscopic virtual environment, augmented by 2D content on additional side screens, so that the system can be used as a kind of 3D visual information system (Zehner, 2010). Figure 1 shows a picture of the system at the top and a sketch of the overall setup with 13 active stereo SXGA+ projectors at the bottom. On the main screen, six projectors are used which provide a resolution of approximately 3800 × 1900 pixels. These, together with three projectors for the floor, provide a virtual environment for the 3D visualization and are run using a computer cluster where each projector has its own computer. For the 3D visualization, the software VRED from PI-VR GmbH is used, which is based on OpenSG, a distributed scenegraph (Reiners *et al.*, 2002). The software runs centrally on a computer (the master computer) that generates the overall scene, changes it, dependent on user input, and also incorporates the tracking information. On startup the scenegraph and subsequently the changes made to it are distributed to the cluster computers (the slave computers) where the actual rendering is done, using OpenGL.

In order to provide additional visualizations on the side wings that are linked to the 3D scene, we have extended our VR Software VRED, using Nokia's Qt Toolkit (Zehner, 2010). We provide two types of 2D windows, map views and data views, with corresponding interaction tools. The data view shows additional 2D data, e.g. the stratigraphic column, upon selection of the borehole in the 3D visualization. The selection is done using a 3D interaction tool, a so-called Flystick, to intersect the borehole with a ray and pressing a button. The corresponding graphics for the 2D visualization is provided to the system as an image. The map view shows a map of Saudi Arabia with an arrow that indicates where in virtual space the users currently are and in which direction they are looking. This helps the users to orient themselves while travelling through the large-scale virtual model by pointing with the Flystick in the direction they want to move and using a small joystick on its top. The 2D-Windows are shown on the system by starting VRED on a computer with several monitors and moving VRED's child-windows which show the 2D visualizations on the second and third monitors. The DVI outputs for these monitors are then connected to a video wall controller which shows the outputs on the side wings of the system (see Fig. 1). If no additional 2D information needs to be shown, the projectors for the side wings can alternatively be run from the computer-cluster and the display can be used as an immersive CAVE-like system.

DATA PREPARATION

In order to show the visualization of the groundwater simulation in our Virtual Environment, the data have to be prepared in a suitable way. The overall workflow for this is shown in Fig. 2. To do

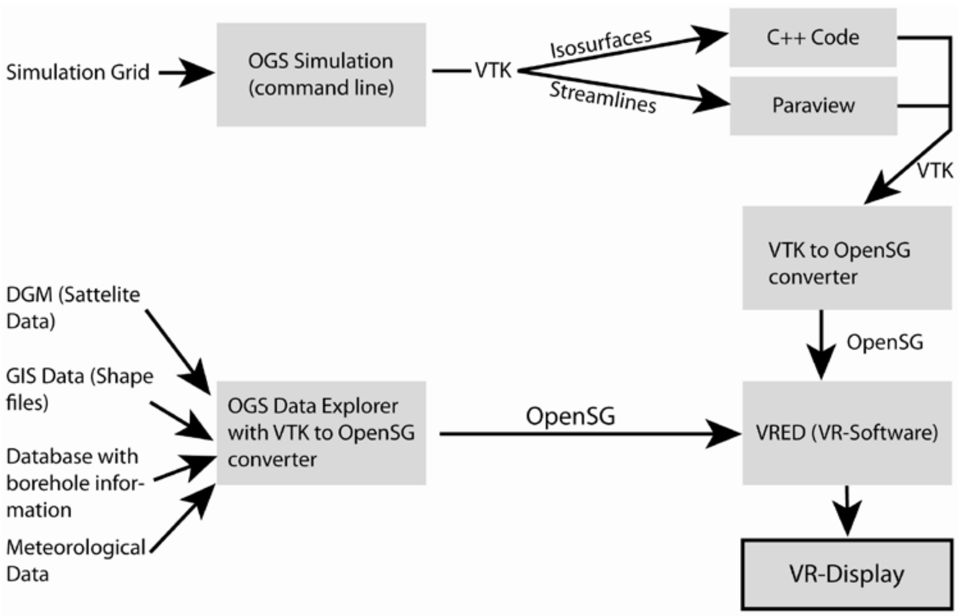

Fig. 2 Data preparation necessary for showing the groundwater simulation in the UFZ's virtual environment. Text in grey boxes indicates the software used. Text outside of grey boxes shows data and their formats.

the finite element simulation, our in-house developed simulation software OpenGeoSys (OGS) which is command-line-oriented has been used. For the scientific visualization of the simulation results we use the open-source C++ library The Visualization Toolkit (VTK, www.vtk.org, Schroeder *et al.*, 1996) and open-source software that is built on top of this library (Paraview, www.paraview.org). VTK also provides its own file format and OGS can directly output the simulation results in this format. The software Paraview or a small application implemented using C++ can than be employed to use different VTK filters, for example to extract isosurfaces for scalar fields or streamlines and glyphs for vector fields. In order to show these VTK-generated objects in our visualization centre, we wrote an extension for VTK that can translate the generated VTK objects into OpenSG objects on the fly, so that they can be shown easily.

One drawback of using a distributed scenegraph, such as OpenSG, is that the time-dependent objects must be distributed over the network in real time, which can put great strain on the network. In our visualization, this is the case for the isosurfaces which represent the hydraulic head, as the scenario we were simulating was to pump from wells for a certain time and then examine how long the water table would need to assume its initial undisturbed position. In order to visualize this time-dependent scenario we generated the isosurfaces for 50 time-steps and translated them into OpenSG objects. These were then placed below an OpenSG Switch node which always shows only one of its children at any one time determined by a number. In this way the 50 different versions of the isosurface are distributed from the master to the slave computers during the startup of the visualization. After that, only the number that determines which frame should be shown needs to be transmitted over the network. This allows for a smooth interactive 3D movie-like representation of the change of hydraulic head (see Fig. 3). As the simulation results were saved in a separate VTK file for each time-step, this conversion was done for practical reasons using a small command-line-driven application that is implemented using VTK and OpenSG. As the vector field hardly changed its directional components, the streamlines have only been calculated for one time-step using paraview and have been subsequently converted to OpenSG.

For the data management of the input data and the model, we use our in-house developed OGS Data Explorer (Rink *et al.*, 2011) which is based on Nokia's Qt Toolkit for GUI development and on VTK for the visualization. We have also integrated our VTK-to-OpenSG converter into this software. We use the Data-Explorer, for example, to convert all kinds of GIS data, such as the digital elevation model, the boundaries of the model region and the structural model, which describes the geology, into OpenSG. Further we have loaded meteorological data that describe precipitation events and converted them into OpenSG. The Data Explorer directly accesses a database that contains the stratigraphic information for all boreholes and generates a 2D visualization of the stratigraphic column as an image for each borehole. These images are then later used for the 2D views. Finally, 3D visualization of the borehole paths is generated directly from their initial GMS format (Groundwater Modelling Software, http://www.aquaveo.com/gms). Figure 2 sketches the overall workflow for data preparation.

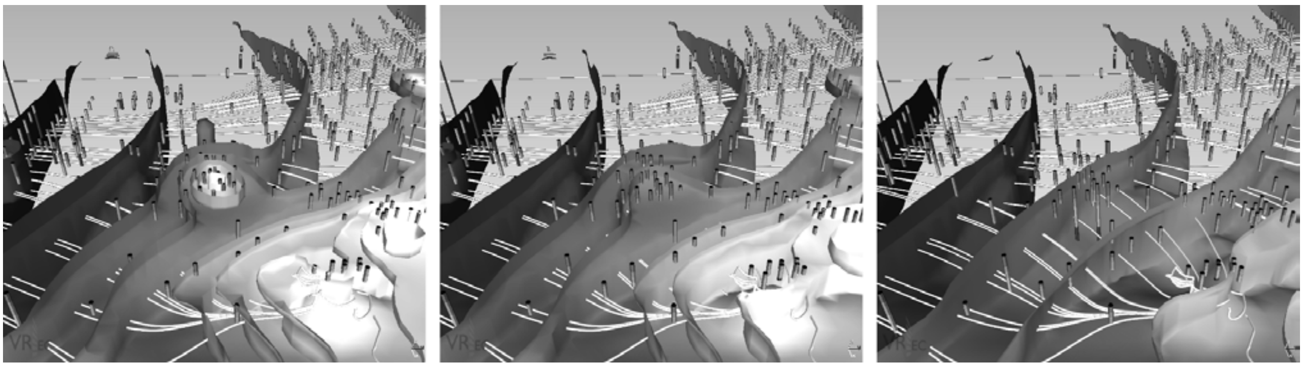

Fig. 3 Three different frames of the visualization depicting the hydraulic head at different time-steps.

RESULTS

The visualization provided has been used to explain the overall problem and the simulation results to stakeholders and other people visiting our visualization laboratory. The time-dependent change of the hydraulic head, rendered as isosurfaces, during the pumping phase and later during the recovery phase, is easy to see, as are the overall water flow directions, rendered as streamlines. Figure 4 shows two people examining the data set. The map view is particularly helpful to viewers, since it always shows them which part of Saudi Arabia they are looking at, and from which direction they are looking, thus facilitating ease of use. The option to directly point with a tool at different items or indicate directions in space enables a more complex and productive discussion of the material to take place.

Fig. 4 Two people discussing the simulation results that are shown as 3D stereoscopic visualization on the rear screen and on the floor using isosurfaces to show the hydraulic head and streamlines to indicate the flow direction. Vertical line structures indicate the boreholes and wells. On the right a 2D view that shows a map of the Arabian Peninsula.

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