IN43B-0628

Application of Virtual Reality Visualization in Integrated Groundwater Modeling

Georgios Kourakos and Thomas Harter

University of California, Davis; Department of Land, Air, and Water Resources One Shields Ave., Davis, CA 95616-8628, United States

University of California, Davis GROUNDWATER Cooperative Extension Program

GROUNDWATER HYDROLOGY · GROUNDWATER RESOURCES · GROUNDWATER QUALITY

http://groundwater.ucdavis.edu

Abstract

Numerical simulation in earth science is a well-established method for explaining and analyzing natural phenomena and forecasting. With the advent of computer technology during the last three decades, researchers are able to carry out computationally demanding simulations on personal computers (PCs). In addition, the numerical models are becoming more complicated requiring a considerable amount input data and produce a large number of output data. In earth sciences the numerical models are extended to three dimensions therefore the input and output data correspond to a 3D space.
Although 3D scientific representation is widely accessible to PCs via the advent of powerful Graphix Processing Units it is still difficult to display, analyze and present 3D complex data via a 2D monitor. To address this issue immersive visualization systems have been developed such as cave automatic virtual environments (CAVE) where multiple projectors are directed to the walls of a room size cube. This requires expensive setup and considerable programming effort.

Over the last decade there is a significant technological advancement in Virtual Reality (VR) Headsets which has also led to production of affordable VR equipment. Along with the hardware development, software development resulted in several libraries that have eased the development of VR applications.
In this work we demonstrate the potential of VR visualization in groundwater hydrology. Groundwater aquifers are inherently 3D applications, and the simulation of groundwater models require considerable amount of spatial input data, e.g aquifer material properties, source and sinks, boundary conditions etc.
In addition, groundwater models result in a large number of output data such as hydraulic head, groundwater velocity, data corresponding to the interaction of groundwater system with other parts of the hydrologic cycle, such as surface water bodies, unsaturated and rote zone etc. Here we explore VR visualization to gain insights into input-output data analysis. Last, given the current constraints in VR rendering, we explore the limits of a low-end VR headset.

Motivation

- The scientific visualization of complex three-dimensional domains is typically achieved via specialized 3D software that are based on rendering two-dimensional images via a hypothetical virtual camera that imitates the user's point of view.
- However, 2D representations of 3D structures limits the amount of data that can be displayed in a comprehensive manner.
- Visualization systems such as CAVEs (Cave Automatic Virtual Environments) offer an alternative approach that allows an immersive experience.
- Those systems require expensive setup and significant infrastructure.
- Here we explore the potential of using common Virtual Reality (VR) Headsets for visualizing a complex three-dimensional Integrated Surface - Groundwater hydrologic model.

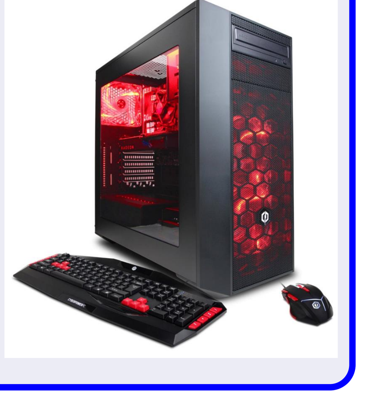
Visualization Challenges

- Commonly used Scientific visualization software such as Paraview (https://www.paraview.org), Visit (https://visit-dav.github.io/visit-website/index.html) etc. can display millions of data by taking advantage of multi-processing.
- 3D graphics software (Blender, Houdini etc) have also been used for scientific visualizations and they can produce very high-quality figures and videos.
- Both options run on PC and can afford temporary freezing (e.g. during loading or processing data). In addition, users can tolerate potential lag for complex data.
- In VR visualizations, freezing or lag is not acceptable as it can lead to VR sickness, nausea etc.
- VR applications must run on 90 frames per second and at worst case down to 60 frames per second.

Hardware Setup

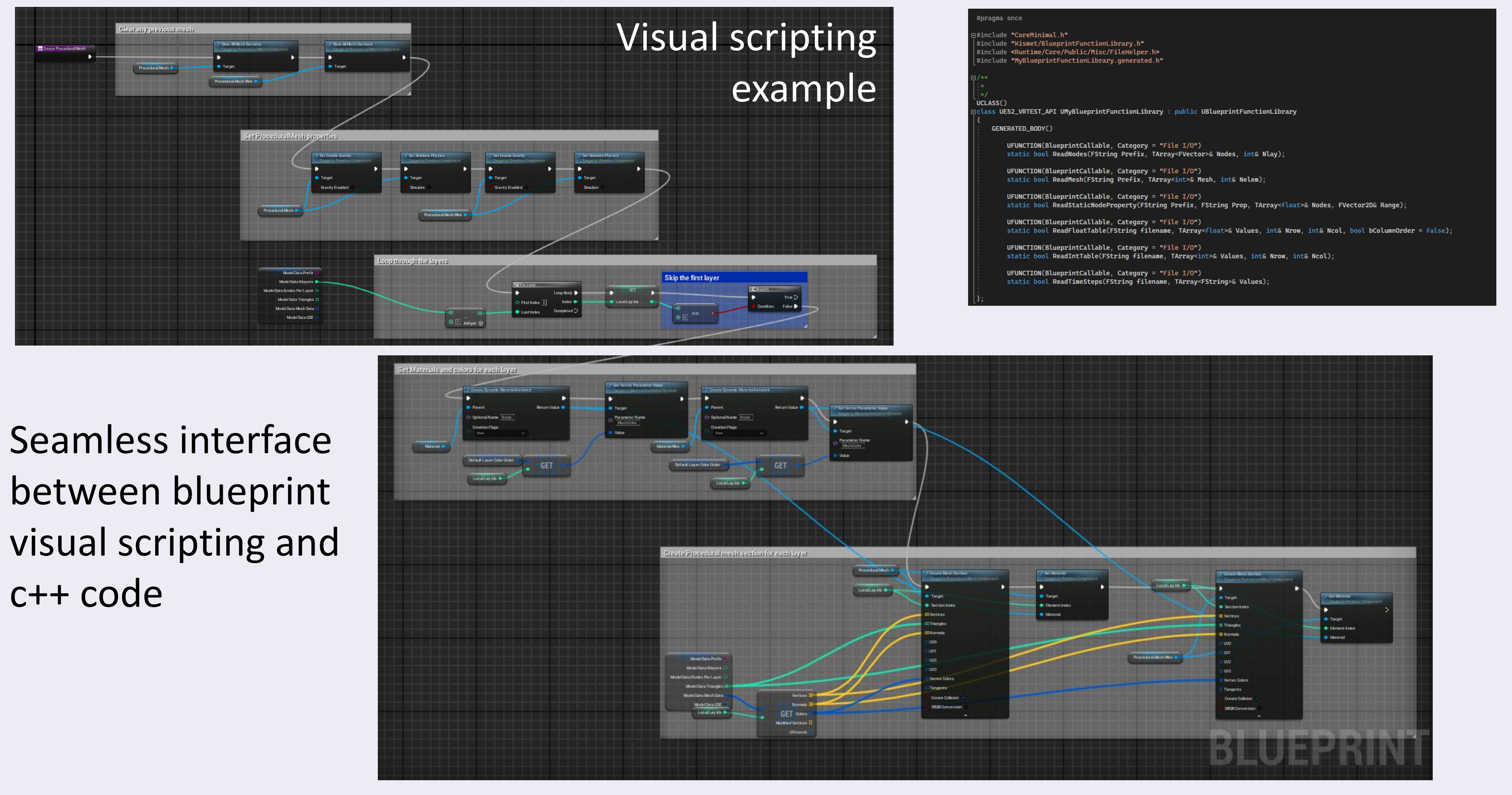
- **Standalone VR headset**
  - Oculus Meta 2
    No cable,
    Portable,
    Suitable for demonstration,
    Packaged visualization
    (cannot update data),
    Limited battery life

- **VR headset tethered to a PC workstation**
  - Oculus Rift S
  - Oculus Meta 2
    Takes advantage of the PC power,
    All the data and rendering processing
    is executed on PCs CPU and GPU,
    Real - time input output,
    No battery



VR implementation

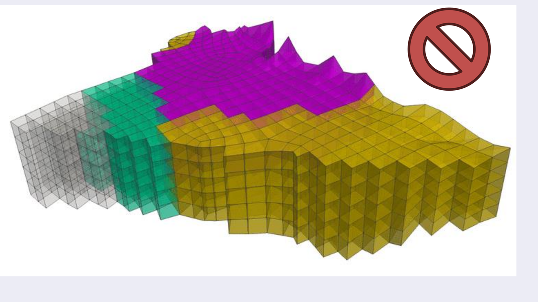
- The visualization application was developed in Unreal Engine 5.2 rendering engine.
- We used a mixed programing style of C++ and blueprint visual scripting.

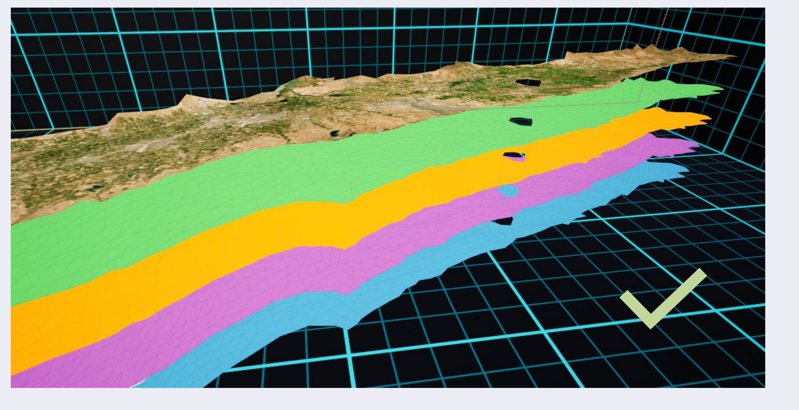


Seamless interface between blueprint visual scripting and c++ code

Hydrologic model data requirements

- Hydrologic models are based on a 3D grid or mesh.
- The data correspond to elements or nodes, and they are usually scalar properties i.e. pumping, recharge or vector i.e. groundwater velocity.
- The data may correspond to all elements, nodes or may correspond to only part of the domain. e.g. precipitation or stream – aquifer interaction are related to the top layer.
- The data can be stationary e.g. hydrologic properties or transient e.g. pumping.

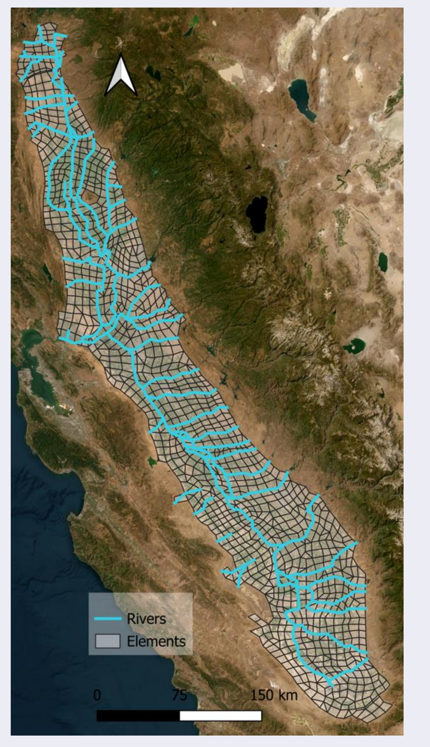


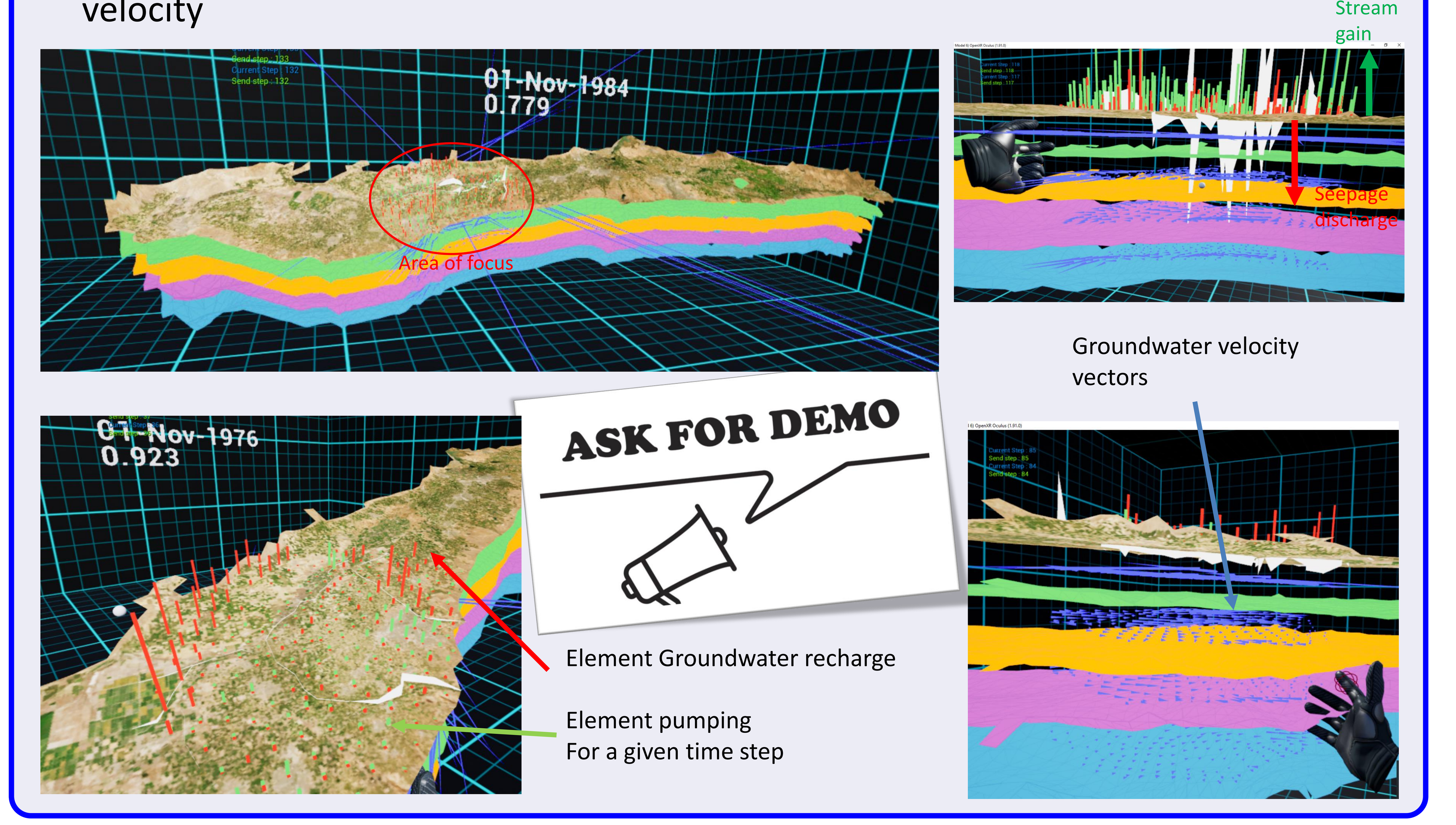


- For the 3D mesh representation, we used a layered visualization approach. Transparency is a computationally expensive operation therefore showing solid semi-transparent mesh is not an option.
- For scalar and vector properties we use very simple **instanced meshes** (cubes and pyramids) with transformation (location, rotation and scale) according to the property values.
- To further improve performance, we developed an approach where properties are displayed on the **area of focus** only where the focus is detected automatically.

Application

- The "California Central Valley Groundwater-Surface Water Simulation Model" (C2VSim) (Brush et al., 2013) simulates water movement through the linked land surface, groundwater, and surface water flow systems in California's Central Valley.
- 1392 Elements and 4 Layers.
- Oct 1973 – Sep 2015 (504 monthly steps).
- The output of the model consist of 5 budgets
  i) Groundwater, ii) Stream budget, iii) Root zoot,
  iv) Surface water, v) Stream Diversion budget.
- In our application we visualized the most important groundwater budget components of Central Valley e.g. pumping, groundwater recharge (natural, irrigated) and stream aquifer exchange. We also plot the groundwater velocity





Conclusions – Next steps

- We developed an initial prototype for scientific virtual reality visualizations with a focus on integrated hydrologic models.
- Practically only tethered setups can be used in research and data exploration.
- In the current version all the processing is executed by the VR application.
- To allow simultaneous visualization of hundreds of properties we disable computationally demanding processes such as lighting, shadows, complex shaders.
- Future improvements will focus on combining the VR application with existing C++ scientific libraries such as vtk, cgal, hdf5, or other codes that can process data independently of the VR application.
- Employing a server – client model so that VR is used for rendering only.
- Developing Interactive user interface.

References
1) Brush, C.F., Dogrul, E.C., and Kadir, T.N. (2013). Development and Calibration of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG. California Department of Water Resources Technical Memorandum, 193 p.

Acknowledgments: Funding for this project was provided by
- **SWRCB Agreement #19-051-250-2**
- **USDA NRCS project NR183A750023C005**

Stay tuned at gwt.ucdavis.edu