TanGeoMS for visualization of subsurface

Introduction

Understanding subsurface conditions like soils properties or geological stratification is hindered by the lack of measured data as well as by the unavailability of models, tools and visualization techniques addressing the complexity of subsurface data. The intrinsic three-dimensionality of the subsurface is often simplified into two dimensions; looking either at the spatial component using standard maps, or at the vertical profiles. Additional information is often presented in the form of charts and tables which are precise, however, they often do not convey the results immediately and in an engaging form.

Geologist and soil scientists are interested in developing modeling and visualizations techniques which would help them communicate their ideas and knowledge with their students and general public (Natali et al., 2014). Interactivity is the key part of such techniques. Stibbard (1997) found that information is absorbed best when using more than one human sense; that is 10 % of the information is taken in by reading, 30 % by reading and visuals, 50 % by reading, visuals and sound and 80 % by reading, visuals, sound and interaction. Currently, researchers are focusing on 3D computer modeling tools using for example Virtual Reality Modeling Language in combination with GIS (Baojun et al., 2009; Grunwald and Barak, 2003), which enable interactive simulations. However, the creation of such models can be tedious and requires advanced computer skills. A growing research interest is therefore in sketching interfaces which allow users to simple draw geological structures and obtain an illustrative 3D model representation of their sketch (Natali et al., 2012, 2014).

Although these techniques can promote understanding of processes and relations, they separate users from the reality by multiple levels of abstraction. Computer visualizations fail to provide tactile feedback, which is both crucial and natural for soil scientists. Löwe and Klump (2013) address this issue by using 3D printer technology to represent individual geologic layers as stacked but separable 3D-prints which can be used as an tangible analogue to block diagram technique. Although 3D printers are becoming more common, they are still limited in terms of the size of the model, price of the

material and time needed for printing the model. So for example printing a time series of dynamically changing soil properties wouldn't be practical.

We would like to propose new technique for interactive visualization of subsurface using Tangible geospatial modeling visualization system (TanGeoMS). TanGeoMS (Tateosian et al., 2010) is designed for collaboratively exploring how landscape change impacts landscape processes. It couples a physical, three-dimensional model with geospatial modeling and analysis through a cycle of scanning and projection. Multiple users can modify the physical model by hand while it is being scanned; by sculpting the model they generate input for modeling of geophysical processes. The modeling results are then visualized by projecting images or animations back on the physical model, providing instant feedback.

Previous applications of TanGeoMS were exploring the impact of terrain modifications on surface-based geophysical processes, such as overland water flow, sediment transport, and also on viewsheds, cast shadows or solar energy potential. However, TanGeoMS can serve as a tool for exploring the subsurface, as well. By creating a physical sand model of a study area and by removing the sand from different parts of the model, we can look under the ground as if we were at an excavation site, and see the actual data represented as a 3D raster in that particular part of the model. Our method represents an intuitive and natural way of exploring subsurface since it imitates to certain extent the real ways of collecting and exploring soils on sites.

Our method can be used as an exploratory visualization tool in soil science to help researchers understand three-dimensional spatial distribution of soil properties and their relationship to landscape. In addition, the proposed method could be beneficial for geology and soil science education thanks to the inherent interactivity which helps students to learn and understand. Further, we can apply the method not just for visualization but also for modeling and decision support. For example, during development, often many areas are graded, uncovering different types of soil which represent a different soil erosion risk. The particular type of soil on those areas can be incorporated into a more sophisticated model which assesses the environmental impact of the development.

The target user groups of this method can be diverse and so are the different types of data which can be visualized using this method. There are

significant differences between continuous soil data properties collected in shallow depths, and stratigraphic data with geological folds abruptly changing the subsurface conditions. We assume that these and similar differences represent different technical challenges for our visualization technique. In the early stage of development, it is important to understand which requirements the different types of data pose in terms of material and size of the model, vertical exaggeration or scanning precision. Such knowledge would help us to focus and develop our technique for certain types of data which are more suitable for the technique and useful for its users.

Methods

Independently of subsurface data type, the main idea of our visualization technique is computing a cross-section of a terrain represented by a physical model with a three-dimensional raster, also called voxel model. The 3D raster represents subsurface conditions where each cell's value describes measured or modeled subsurface phenomenon. The 3D raster values can be either continuous, or categorical; continuous values are typical for interpolating from discrete measurements while categorical data are used for example for classifying different stratigraphic layers.

In order to apply this method, we have to first process the data to have it prepared in the form of 3D raster, and build a physical model of the landscape from some malleable material such as sand. Then, by removing sand from different parts of the model, user alters the landscape which is then scanned and imported into GIS where we create a digital elevation model (DEM). By computing a cross-section of the DEM with the prepared 3D raster we obtain a raster which is then projected back on the model. Users can then immediately see the values represented by different colors or color gradient where they have previously removed the sand.

Based on preliminary results from testing this method, we can identify a few issues related to the visualized data and its type. The most prominent one is how to deal with completely different horizontal and vertical exaggeration of subsurface data. This property is typical for soil data which are often measured in shallow depths around 1 meter, but the distance between the sampling locations is of the order of magnitude higher. As a result, we have to vertically exaggerate the modeled landscape to be able to represent the

height of the 3D raster in a reasonable scale, which means typically at least a few centimeters. Depending on the horizontal scale of the modeled area and the maximum depth of soil samples, we can compute the vertical exaggeration which would be in most cases very high, ranging from ten to one hundred. Relatively flat area could then look unrealistically hilly and even lead to false assumptions about the data.

Stratigraphy data could be visualized with TanGeoMS as well. Since the geologic structures are often located in a larger depth than soil data, the vertical exaggeration does not seem to be an issue. Stratigraphic data are often more variable in the vertical dimension than in the horizontal; therefore to explore the stratigraphic layers we need to create deep holes in the sand model, not just shallow depressions. Here we have to take into account the capabilities of the scanner to scan such places accurately. We assume that the more deeper the hole is, the more open and wide it should be so that the scanner scans the surface correctly and the projected image is not completely distorted.

In terms of material, sand models seem to be currently the best option because sand is easy to shape. Comparing to models carved with a CNC router, sand models cannot be as precise, which results in cross-sections going just slightly under the ground in certain parts of the model where there is no apparent depression. Using a mold to create an even layer of sand on top of a carved model might help to achieve more precise results.

The suitability of different types of subsurface data, and other factors such as model size or material will be tested during the development of our method. We will try to address the identified issues, for example with soil data requiring high vertical exaggeration, we could in certain cases declare the landscape to be completely flat to avoid the negative effects of the vertical exaggeration. We hope that such testing would reveal not just other difficulties but also provide some insight into their solutions so that we can in the future try to use this method as a more general visualization tool for any 3D raster.

References

Baojun, W., S. Bin, and S. Zhen (Aug. 2009). "A simple approach to 3D geological modelling and visualization." In: *Bulletin of Engineering Geology and the Environment* 68.4, pp. 559–565. ISSN: 1435-9529. DOI: `10.1007/s10064-009-0233-y`. URL: `http://link.springer.com/10.1007/s10064-009-0233-y`.

Grunwald, S. and P. Barak (Mar. 2003). "3D Geographic Reconstruction and Visualization Techniques Applied to Land Resource Management." In: *Transactions in GIS* 7.2, pp. 231–241. ISSN: 1361-1682. DOI: `10.1111/1467-9671.00142`. URL: `http://doi.wiley.com/10.1111/1467-9671.00142`.

Löwe, P. and J. Klump (2013). "3D printouts of geological structures, land surfaces and human interaction - an emerging field for science communication." In: *8th International Symposium on Archaeological Mining History*.

Natali, M., I. Viola, and D. Patel (Aug. 2012). "Rapid Visualization of Geological Concepts." In: *2012 25th SIBGRAPI Conference on Graphics, Patterns and Images*, pp. 150–157. DOI: `10.1109/SIBGRAPI.2012.29`. URL: `http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6382751`.

Natali, M., T. G. Klausen, and D. Patel (Mar. 2014). "Sketch-based modeling and visualization of geological deposition." In: *Computers & Geosciences* 67, pp. 40–48. ISSN: 00983004. DOI: `10.1016/j.cageo.2014.02.010`. URL: `http://linkinghub.elsevier.com/retrieve/pii/S0098300414000508`.

Stibbard, A. (1997). *Warwick University Forum*.

Tateosian, L., H. Mitasova, B. A. Harmon, B. Fogleman, K. Weaver, and R. S. Harmon (Jan. 2010). "TanGeoMS: tangible geospatial modeling system." In: *IEEE transactions on visualization and computer graphics* 16.6, pp. 1605–12. ISSN: 1077-2626. DOI: `10.1109/TVCG.2010.202`. URL: `http://www.ncbi.nlm.nih.gov/pubmed/20975203`.