Natural Science Visualization Using Digital Theater Software

Adapting existing planetarium software to model ecological systems

Rachael Luhr[1,3], Derek Reimanis[1], Renee Cross[1,3], Clemente Izurieta[1,3], Geoffrey C. Poole[2,3], Ashley Helton[4]
[1]Software Engineering Laboratory, Department of Computer Science, Montana State University
[2] Land Resources and Environmental Sciences Department, Montana State University
[3] Montana Institute on Ecosystems
[4] Department of Biology, Duke University

{rachael.luhr, derek.reimanis, renee.thibeault}@msu.montana.edu, {clemente.izurieta, gpoole}@montana.edu, amh72@duke.edu

***Abstract*—Data in the natural sciences can often be dense and difficult to understand. The process of visualizing this data helps to alleviate these issues. In this paper, we demonstrate how using digital theater software built for planetaria can be an appropriate medium in which to facilitate these visualizations; not only because of the software's complex and comprehensive graphics engine, but also as a means to convey the information this data is representing to the general public in way that is understandable, accessible and enjoyable. We exemplify the use of this technology through a case study where the simulation of water molecules in the Nyack Floodplain on the Middle Fork Flathead River, are visualized with dome technology.**

Keywords— smart media, 3D planetarium content, digital theatre, flux networks

I. Introduction

Digistar 4 is digital theater software produced by Evans & Sutherland [1] for use in planetariums. The platform has an easy-to-use interface to complement its complex graphics and physics engine. This allows the software to be used by non-experts to create planetarium shows that educate and entertain the public. This type of visualization tool could be applied to other areas of science for the purposes of new discoveries, education and community outreach. In the past few years, there has been collaboration between the Computer Science Department and the Department of Land Resources and Environmental Science at Montana State University in an effort to visualize complex ecological data. This representation eases the otherwise non-intuitive process of understanding the spatiotemporal dynamics commonly found in ecological models. This effort was successful and helped seed the idea that Digistar 4 can be used as a tool to help to comprehend complex data-intensive phenomena that are difficult to conceptualize otherwise.

This paper is organized as follows: Section II outlines the background information regarding the modeling framework and previous work in visualization, Section III explains the methodology used to develop and display the visualizations of the models, as well as the case study in the Nyack Floodplain used to exemplify this work. Section IV details the outreach opportunities available when using this technology, and Section V describes future uses of this technology.

II. Background

A. Visualization of Scientific Models

Natural, social and engineering phenomena frequently exhibit strong spatial and/or temporal trends and interactions. Understanding these causal relationships between components and their evolutionary trajectories is the underpinning of a large number of domain sciences. As environmental data sets become larger and denser, effective exploration and pattern analysis becomes a critical bottleneck in analytical reasoning that can hinder decision making [2].

"Data visualization is a dynamic discipline in order to quickly react to new developments in graphics hardware, virtual environments or network technology, to new computer graphics algorithms, and last but not least to the ever growing size of scientific datasets" [3]. Scientific data is difficult to understand for those who are not familiar with the specific field and research being done. The more complex models built by simulation software are even more difficult to understand. These models are often represented by long lists of information or matrices of numbers, which make this type of data difficult to comprehend. Visualizing these numbers helps to share the knowledge and discovery of scientific research to those outside the specific field. This can be useful for education, community outreach, grant proposals and research funding.

B. Network Exchange Objects

Network Exchange Objects (NEO) is a simulation framework under development at Montana State University [4]. NEO facilitates the development of simulation models that describe the behavior of complex systems – specifically the flux and storage of multiple interactive "currencies" through systems represented as networks. A currency is anything within the model that is being exchanged between components or the modeled system (e.g., energy, economic capital, genes, carbon, nutrients, or any other resource of interest, depending on the system). Currencies are manipulated as they flow between nodes and edges in the network, representing the effect entities have on the flow.

978-1-4799-0604-8/13/$31.00

NEO is designed to study systems that can be described as "complex adaptive hierarchical networks" (CAHNs). A CAHN is implemented with a graph *G* and uses a combination of network theory, complex systems theory, hierarchy theory, and interdependency idioms to characterize the structure and behavior of a model built atop this network (*G*) of interconnected nodes and edges. The implementation of these four characteristics of natural systems in NEO allows scientists to investigate (1) patterns that emerge from network connections, (2) interactions among system components, specifically the interactions of flow through nodes/edges, (3) hierarchical structure as it affects interaction, and (4) the effect on the model caused by currency interdependency [4].

III. Methodology and Case Study

The focus of our work involves leveraging the powerful features of the Digistar 4 framework to create working visualizations of ecological models. We designed a system to significantly reduce the effort required to handle the transfer of information resulting from simulations that ran in the NEO simulation environment to the Digistar 4 system. The interface to facilitate transfer of information was written using the Java language. Its functionality allows for the parsing of text or comma delineated files to extract the necessary information necessary to exercise the Digistar4 visualization engine.

The visualized models represent the movement of currencies in flux networks. That is, the models exhibit complex behavior through multiple data of different types flowing and interacting through the system. The following case study describes the successful visualization of water molecules that represent a single currency in the Nyack Floodplain on the Middle Fork Flathead River. The river channel, floodplain surface and aquifer (structure) and the movement (behavior) of water (currency) were modeled using NEO.

To understand how different river compartments affect downstream transport times through the Nyack study site, Helton et al. [8] simulated water flow within and among the channel, subsurface, and floodplain surface hydrologic system. A three dimensional model (shown in Figure 1) was constructed from the site (shown in Figure 2).

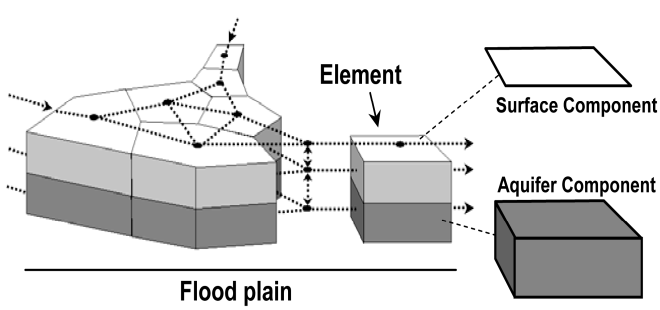

Fig. 1. Inter-connected components of the river [7]. Figure Copyright © 2004 John Wiley & Sons, Ltd. Reproduced by permission.

The floodplain is divided into spatially discrete patches, represented by nodes connected in a three dimensional network. Edges represent the connections to neighbor patches. The model represents horizontal water flow; horizontal and vertical subsurface flows; and vertical exchanges between subsurface and surface waters. Equations used to represent physical principles behind the water flow are described by Walton et al. [6] and Poole et al. [7].

The output of the model was then visualized with the Digistar 4 planetarium engine. Figure 2 shows the end result; an aerial image of the Middle Fork Flathead River, taken from Google Earth [5], that is superimposed behind the modeled floodplain structure of the Middle Fork Flathead River.

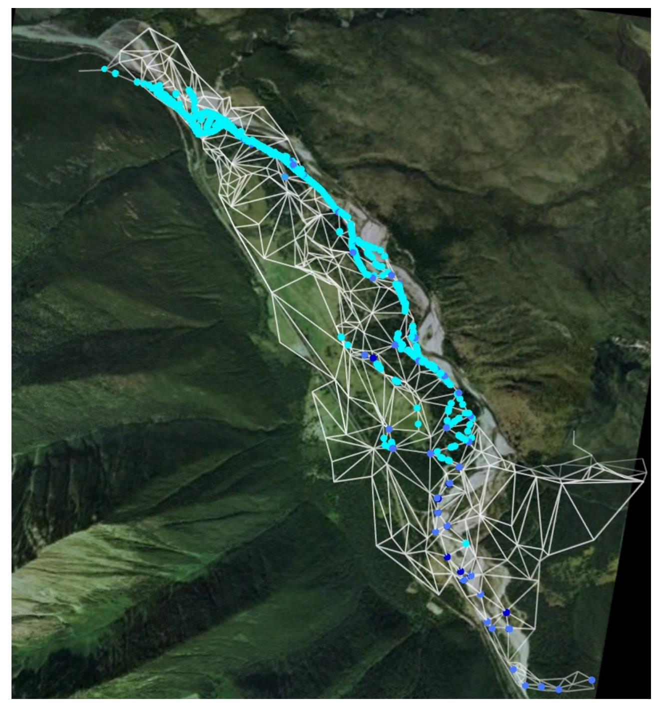

Fig. 2. Single frame from an animated visualization of surface- and groundwater flow through the Nyack Floodplain of the Middle Fork Flathead River, Montana, USA. Light blue dots shows surface water molecules; darker blues represent groundwater molecules with increasing depth.

Although being able to visualize models with only one moving currency is instrumental in understanding the data, the outputs produced from complex simulations contain many currencies that not only interact with each other, but may also operate at different time steps. We developed the functionality to handle the visualization of multiple currency flows. Multiple currencies are necessary when modeling behavioral aspects of dynamic systems such as those found in the natural sciences. Multiple currency support allows scientists the ability to visualize the complex interacting behaviors inherent in complex adaptive hierarchical networks (CAHNs) and enhance the accuracy of the model.

Using the Digistar 4 system framework, we can also adjust many aspects of the currencies, such as color, opacity, and flow rate. For example, to visualize the data from a river system that includes two currencies, i.e., water flow and heat exchange, we enhanced the Digistar 4 with the functionality to turn the color of the water currency blue and the color of the heat currency red. This helps improve the interpretation of the visual data. Also, if a model contains multiple currencies but only one of those currencies needs to be analyzed, we can set the opacity of the unneeded currency to zero. This maintains the integrity of the model while giving us control over what we wish to visualize. Further, we also added the ability to slow or speed the rate at which currencies flow through the system.

Different currencies will likely move at different motion rates, so having the ability to set different motion rates is also an invaluable tool in visualizing this data. Because different currencies are input into Digistar 4 as separate data files, we are easily able to manipulate individual attributes of the currencies. This work is still in progress, but has been initially realized in a simple visualization of a cube (Figure 3). The currencies represented in this cube are different colors and sizes, and are moving at different rates of speed.

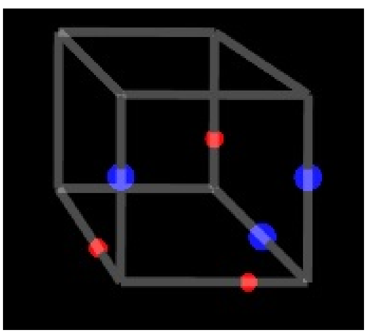

Fig. 3. Visualization of multiple currencies through a cube-shaped matrix.

Other adjustable aspects of the model include changing the depth (z-scale) of the structure of the model. In the Nyack Floodplain model, where the depth of the water molecules is also important, exaggerating the z-scale allows ecologists to view the model in a different way. The floodplain is very long and wide, so in order to accurately represent it in its entirety, the depth appears to be fairly shallow. When the model is rotated so a cross-section can be seen, and we adjust the z-scale so the water-bed becomes deeper, then, not only can ecologists study the flow of the water molecules downstream, but they can also examine how deep the molecules flow into the gravel aquifer underlying the stream channel, and how long the water remains there.

IV. Outreach

The use of the Digistar System allows for opportunities above and beyond those that accompany ordinary modeling software. The use of this software allows for a effective outreach opportunity that makes connections beyond the scope of our lab and research group. We have the ability to display our visualizations at a museum planetarium; a public venue with 3D projection capabilities and where 60,000 people pass through to view shows on a yearly basis. These capabilities provide us with the chance to communicate science and our research to those in academia as well as the general public, and to bring awareness to the dynamics of ecosystems and changing landscapes due to climate change or other factors. There is also the potential to target youth groups with the intent to stimulate interest in science and computing fields.

This outreach potential also allows for the interdisciplinary collaboration between not only Computer Science, Land & Resource Sciences, and the museum, but also the School of Film & Photography. It is one of our future goals to make a professional documentary of the research that is currently taking place that will display current and future visualization products. These endeavors will be beneficial for communicating our research to the public, stakeholders, and groups whose mission is to advance the field of environmental science. One of these such groups is the Montana Institute on Ecosystems, a program created under the NSF EPSCoR Track I project whose mission is to stimulate research in the environmental sciences and engineering while addressing climate change effects in sustaining healthy ecosystems. Using software of this type to visualize these complex ecological models will help to understand links between landscape and processes in a way that will be visually stimulating and captivating. With the use of this software for our modeling purposes, one can "step inside" the simulation of a river or ecosystem element and see for themselves a flow network in action or the effects of changes made within that network.

V. Future Work

There is still much work to be done with the visualization of multiple currencies. Currently, the only model featuring multiple currencies is the simple cube matrix. However, in order to create these multiple currency visualizations using real ecological data, we need to more seamlessly integrate the NEO simulation framework with the Digistar system. This would allow for the ability to output data directly from the NEO database and input the data into Digistar 4 with minimal intermediary formatting changes. There is also preliminary research focusing on the improvement of the accuracy of water molecule movement in hydrogeology models, similar to the one of the Nyack Floodplain.

As noted in the previous section, we would also like to extend the outreach of our visualization efforts. We plan to put together a short clip of the water molecule movements to be shown in the Taylor Planetarium. This clip would reach thousands of viewers of all ages and would highlight the work being done here at MSU.

Acknowledgements

First, we would like to extend our gratitude to Evans & Sutherland for the use of the Digistar system as well as the engineering support provided. We would also like to thank the Taylor Planetarium and the Museum of the Rockies for giving us their time and access to the planetarium. This work was funded by the Undergraduate Scholars Program at Montana State University and the National Science Foundation (NSF) under grant award 1021001. The Montana Institute on Ecosystems is also responsible for supporting this work.

REFERENCES

[1] Evans & Sutherland [online] 2011, http://www.es.com (Accessed: 25 March 2013).

[2] Buneman, P., Chapman, A., Cheney, J., 2006. Provenance Management in Curated Databases. ACM, pp. 539-550.

[3] Ebert, D., Favre, J., Peikert, R., "Data Visualization." *Computers & Graphics* 26.2 (2002): 207-08. Print.

[4] Izurieta, C., Poole, G.C., Payn, R.A., Griffith, I., Nix, R., Helton, A., Bernhart E., Burgin, A.J., "Development and Application of a Simulation Environment (NEO) for Integrating Empirical and Computational Investigations of System-Level Complexity." In Information Science and Applications (ICISA), 2012 International Conference on (pp. 1-6). IEEE.

[5] Google Earth [online] 2013, http://www.google.com/earth/index.html

[6] Walton, R., Chapman, R.S., Davis, J.E., "Development and application of the wetlands dynamic water budget model," Wetlands 16:347-357, 1996.

[7] Poole G.C., Stanford J.A., Running S.W., Frissell C.A., Woessner W.W., Ellis B.K., "A patch hierarchy approach to modeling surface and subsurface hydrology in complex flood-plain environments," Earth Surface Processes and Landforms 29:1259-1274, 2004.

[8] Helton A.M., Poole G.C., Payn R.A., Izurieta C., Stanford J.A., "Relative Influences of the River Channel, Floodplain Surface, and Alluvial Aquifer on Simulated Hydrologic Residence Time in Montane River Floodplain," Elsevier Journal of Geomorphology. 2011.