Color Rapid Prototyping for Scientific Visualization: Diffusion Tensor MRI Visualization and Topographical Exploration of Mars

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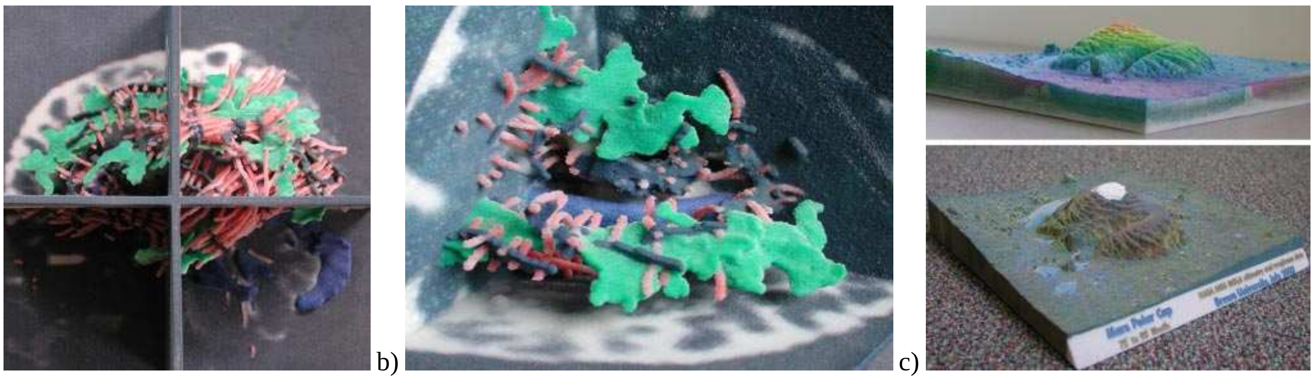

a) b) c)

Figure 1: (a,b) 3D print-outs showing areas of linear and planar water self diffusion, red tubes and green surfaces respectively, obtained from DT-MR images. (c) Two 3D models created based on topographic data from Mars. The top image shows a color coded height field model while the bottom one th same terrain with information about the roughness of the topography.

We describe work toward creating physical three-dimensional color models as visualization tools to support scientific research in Diffusion Tensor (DT) MRI visualization and terrain visualization of Mars (figure 1). We provided scientists with Virtual Reality applications to visualize different aspects of their brain and terrain data, but having physical representations of those virtual models allows them to quickly review the data with a very robust, natural, and fast haptic interface: their own hands. Our initial results are encouraging. End users, neurologists and geologists, are excited about the possibilities these creations give them. For example, using them in conjunction with digital models, they provide a static frame of reference that helps keep the users oriented during their analysis.

The Data: DT-MRI. We are looking at the geometric models generated from a DTI dataset. The red streamtubes represent the diffusion in linear anisotropy regions, where water primarily diffuses in one direction. The direction of a tube represents the principle direction of diffusion along the tube. Studies show that there is correlation between the structures of neural fibers in white matter and the tracts derived from the principle direction of diffusion in linear anisotropy regions. The green surfaces are generated in planar anisotropy regions, where water diffuses primarily in a small plane at any given point. The surface structures could be the result of crossing fibers or laminar structures. Besides the geometric models, we also show some anatomical features that put the new geometric representation in a context that is familiar to the doctors. The blue surface shows ventricles, and the images on the three orthogonal planes show slices of T2-weighted images collected with the DTI.

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The Data: Mars. We are looking at color-sliced altimetry of the north polar region of Mars, vertically exaggerated to show the topographic features and their interrelationships. Features include the north polar cap, the northern lowlands basin in which it sits, and the deposits filling the north polar basin. The structure of the north polar cap includes troughs, which are believed to be related to sublimation on equator-facing slopes by incident solar radiation and redoposition on pole-facing slopes, and thus lateral migration of troughs. Perspective views of these troughs will enable us to readily test these models. A large valley or chasma, extends from the central part of the cap to the outside. Known as Chasma Boreale, this is thought to have been eroded by accumulating melt-water at the base of the cap, and subsequent outflow, perhaps catastrophically. The 3D model helps us to assess this hypothesis in relation to depth of source pits, topography of the chasma floor, and characteristics of the lobate deposit at the termination of the valley. Furthermore, there is a lower plate unit at the base of the cap that may be the source of the sand dunes in the surroundings and the relatively smooth crescent-shaped deposit at the margin of the cap. This portrayal will help us test this idea and predict where this unit might be exposed. The floor of the basin is the site of an ancient standing body of water formed by the major outflow channels from the south. We are currently assessing the properties of the deposits and their relationships to the formation and growth of the present polar cap. The 3D model helps in this perspective.

The Printing Process. We use Z-Corp's Z406 printer [6] to create our color models. The process is as follows: The digital model, in VRML format, is subdivided into horizontal layers by the printer software. These layers are then formed by putting down a thin layer of plaster powder and dropping colored binder where the boundaries of the model are at that level. Once all the layers are built, the powder outside the boundaries of the model is vacuumed out.

Then, using a fine blower, the loose powder in-between the resulting model is removed. The printing process takes about twelve hours for the more complicated brain models. The cleaning takes about two hours. Finally, the piece receives a hot wax bath to increase its structural resistance and enhance its colors.

The models created with the Mars data are simple and the process is very straight forward. On the other hand, the structures in the DT-MRI models require very careful treatment. Because the long skinny streamtubes often fail to support themselves during the powder-removing process, we had to insert some supporting surfaces that connect neighboring streamtubes together. These are created from the second and third eigen-values of the diffusion tensor that creates the streamtubes, so they are perpendicular by definition. We reached this methodology after several tests, which included building thicker tubes or increasing the ammount of them so they supported each other.

Related Work. The use of RP for visualization has concentrated on building molecular models to test assembly possibilities [1,2,3]. Clark et al. [4] used physical semi-transparent terrain models to visualize information by rear-projecting images onto them. Nadeau et al. [5] created models of the human brain's surface using the same RP techniques we use. The main difference is that we build inner brain structures, not the outside surface.

Lessons Learned. During our initial experimentation we found that the main advantages of this technology for scientific visualization are:

- Users are familiar with physical models and recognize the usefulness of being able to use the sense of touch in studying them.
- The data visualization is not dependent on computing power. The frame rate does not drop for more complex models.
- Providing scientists with these models leads to a much better usage and analysis of their digital counterparts. *"These physical models complement displays in digital format by providing a hard-copy frame of reference that can be touched and manipulated with optimum hand-eye coordination and immediate results"* – Prof. James Head III, Department of Geological Sciences, Brown University.

On the other hand, these early stages of development have highlighted some of the issues of this type of technology:

- Our visualizations deal with organic, free-form shapes, whereas current RP technology is designed for relatively simple models. We need to work on redesigning the process for our specific needs. For example, color is very important and current technology does not always provide the same results when creating multiple copies of the same model. Further investigation on materials and binders needs to be done to address the strength issues our complex models have.
- Since the pieces need to be structurally sound, the extra support needed might obstruct the view of the real data being visualized.
- The printing process took up to 12 hours for complicated models of the brain. The handling of texture mapping in the printing software is not well implemented and breaks down when dealing with otherwise simple texture maps.
- The maximum size of the printed models can only be 8"x8"x10", with a maximum resolution of approximately 250 dpi. Some models would need to be larger due to higher resolution data, which would require tiling the models and putting the pieces back together afterwards.
- For scaled models some extra cues need to be added to convey the correct sense of scale.

Figure 2: Detail of support structures (dark gray) for the streamtubes. These surfaces are created using the second and third eigenvalues of the same tensors that produce the tubes.

- Changes in the data being visualized require a whole new model to be created. Clark et al. [4] addressed this by making semitransparent models.

Conclusions and Future Work. For the brain models, we added support structures to help stabilize the models. At the same time we tried to minimize their impact, since those structures could occlude interesting features. This balancing has occuppied most of our experimentation so far. Using information already present in the DT-MRI data, we have been able to create structurally sound models (see figure 2).

Finally, the fact that we have these two visualization facilities, our VR CAVE environment and the RP machine, creates the very real possibility of connecting them: using the RP facility as a back end output for the visualizations and experiences taking place in our virtual reality installation. At the same time, models built using these techniques could be brought back into the virtual environments as physical props. We envision users holding in their hands miniature models of the virtual scenarios they are immersed in, or designing and building new interaction devices using RP technology.

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This work was partially supported by NSF (BCS-9980091, CCR-0086065, EIA-9724347, EIA-8920219, CCR-0093238) and Human Brain Project (NIDA, NIMH). Opinions expressed in this paper are those of the authors and do not necessarily reflect the opinions of the NSF.

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[3] M.J. Bailey, K. Schulten, and J. Johnson. The Use of Solid Physical Models for the Study of Macromolecular Assembly. Current Opinion in Structural Biology, vol. 8, no. 2, April 1998, pp. 202-208.

[4] D. Clark, R. Marciano, R. McKeon, and M.J. Bailey. Rear-Projecting Virtual Data onto Physical Terrain. Proceedings of the IEEE Visualization '98 Conference, October 1998.

[5] D. R. Nadeau, and M. J. Bailey. Volume Visualization using Physical Models. Proceedings of IEEE Visualization 2000, October 2000.

[6] Z Corporation. http://www.zcorp.com

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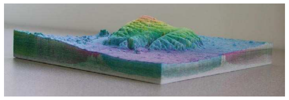
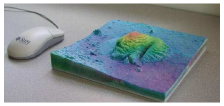
a)



(b

c)



Mars Orbiting Laser Altimeter

We are looking at color-sliced altimetry of the north polar region of Mars, vertically exaggerated by a factor of 10 (b,c) to show the topographic features and their interrelationships. Features include the north polar cap, the northern lowlands basin in which it sits, and the deposits filling the north polar basin. Surface roughness is also represented (a). The structure of the north polar cap includes several troughs, and the 3D models help us assess hypotheses about their origin and developement.

Contributions

We are building physical three-dimensional color models as visualization tools to support scientific research in DT-MRI visualization and terrain visualization of Mars.

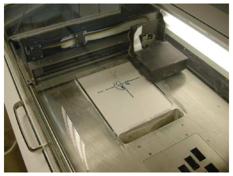
We have identified important issues in the application of RP technology for building scientific models in these areas.

Due to the structure of the brain models we are building, extra support structures were needed to avoid their general collapse. This was solved by using previously unused components of the diffusion tensors, thus not requiring non-data related elements.

We have successfully engaged users into a productive discussion of the use of these physical models for their research. More specifically, they are using the Mars print-outs as orientation aids when exploring digital topography models on the desktop and CAVE.

Our Printing Process

We are using Zcorp's Z406 printer. The digital model, in VRML format, is subdivided into horizontal layers. These layers are then formed by putting down a thin layer of plaster powder and dropping colored binder where the boundaries of the model are at that level (a). After the model is finished, the powder outside the model is vacuumed out (b,c). Then, using a fine blower, the loose powder in-between the final model is removed (d). The printing process takes about twelve hours for the more complicated brain models. The cleaning takes two hours. The piece receives a hot wax bath to increase its structural resistance and enhance its colors (e, f).



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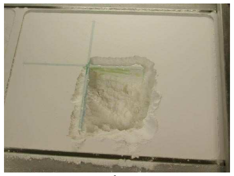
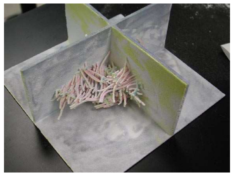


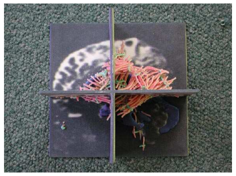
b

c

d



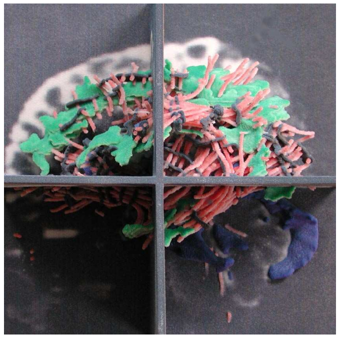
e



f

DT-MRI Visualization

We are looking at the geometric models generated from a DTI dataset (a). The red streamtubes (c) represent the diffusion in linear anisotropy regions, where water primarily diffuses in one direction. The green streamsurfaces (c) are generated in planar anisotropy regions, where water diffuses primarily in a small plane at any given point. The blue surface (a,d) shows the ventricles, and the images on the three orthogonal planes show the slices of T2-weighted images collected with the DTI.
Because the long skinny streamtubes often fail to support themselves during the dust-removing process, we also insert some supporting surfaces that connect neighboring streamtubes together, shown as the gray surfaces in the model (d). We removed part of the base of the model to access the inside (b).



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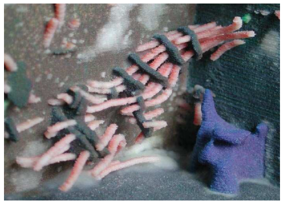

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Rapid Prototyping strengths

* Users are familiar with physical models and recognize the usefulness of being able to use the sense of touch in studying them.
* The data visualization is not dependent on computing power. The frame rate does not drop for more complex models.
* Providing scientists with these models leads to a much better usage and analysis of their digital counterparts. *"These physical models complement displays in digital format by providing a hard-copy frame of reference that can be touched and manipulated with optimum hand-eye coordination and immediate results."* -- Prof. James Head III, Dept. of Geological Sciences, Brown University.

Issues using Rapid Prototyping

* We are using machines designed for other types of models. We are building more organic, free-form shapes. The technology was not developed for these models and current materials don't support fragile structures very well.
* Since the pieces need to be structurally sound, the extra support needed might obstruct the view of the real data being visualized. Balancing these two factors takes many iterations of the printing process.
* One printout takes up to 12 hours for a complicated model of the brain.
* Texture mapping is not well implemented in the printing software.
* The maximum size of the models can only be 8"x8"x10". Larger models require tiling the pieces and putting them back together afterwards.
* Scaled models require extra cues to convey the correct sense of scale.
* Changes in the data being visualize require a whole new model to be created.
* Color is very important and current technology does not always provide the same results when creating multiple copies of the same model. Further investigation on materials, inks, and hardware needs to be done.

What's next

* We will connect the RP facility with our VR environments to use it as an output for scientific research.
* We will extend the use of 3D physical models as input devices in our CAVE, Powerwall, and Fishtank-VR facilities.