CREATING TACTILE CAPTIONS IN THREE-DIMENSIONAL COMPUTER-AIDED DESIGN

Stewart Dickson, Visualization Researcher
Computer Science and Mathematics Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6016
Email: Dicksonsp@ORNL.gov
URL: http://www.csm.ornl.gov/~dickson

ABSTRACT

Vision-limited people, people with cognitive or learning disabilities, even people with no such limitations can benefit from casting the results of scientific computing into physical form using computer-interfaced rapid prototyping "3-D printers."

The author presents work to date on mathematical concretization and applying tactile captions to 3-D models in-the-round.

The author also presents software and techniques for composing DotsPlus(tm) Braille text in a three-dimensional Computer-Aided Design (CAD) and rapid-prototyping system.

Keywords: Visualization, Tactile Feedback, CAD, Computer-Aided Manufacturing (CAM), Braille, Computer-Aided Text Formatting

Research sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC for the U.S. DOE under Contract No. DE-AC05-00OR22725.

BACKGROUND AND MOTIVATION

When one makes an image of a multi-dimensional computational problem, one transforms the abstract information into a form accessible to a different sensory modality, opening the problem to interpretation from a different point-of-view. This often leads to unexpected discoveries in a system which was previously only accessible through a highly abstract means. [1]

The author has demonstrated transforming the abstract language of pure mathematics directly into three-dimensional, physical form using the mathematical compiler of natural, mathematical language and several other three-dimensional computer-aided designs and manufacturing techniques. [2][3]

It should be obvious that taking the results of visual computing from behind the monitor screen and into three-dimensional, tactile form makes these results accessible to those who cannot see through a transparent surface.

For example, in 1998 George Francis, John Sullivan and Stuart Levy created a film, titled "The Optiverse," based upon a computer simulation of the Morin sphere eversion. [4] An eversion is the idea of mathematically turning a sphere inside-out without cutting it. This eversion was conceived by Bernard Morin, a mathematician who has been blind since an early age.

The work of Francis et al. employed a surface bending energy minimizing constraint which modified the geometry of the eversion from the form Morin had originally conceived. Because Morin could not see the visual results of the computer simulation, he had no concept of how the geometry was changed.

In the year 2000 the author, with John Sullivan and Stuart Levy created physical models of four phases of the Optiverse computer metamorphosis at a scale of about eight inches in epoxy resin using the Stereolithography rapid prototyping or "3-D printing" technology. [5]

The author presented these models to Professor Morin at which point he was immediately able to understand the changes Sullivan et al. had made to the geometry.

Manufacturing physical models of the three-dimensional results of scientific and mathematical computation also affords the opportunity to re-integrate abstract information into the visualization, which is frequently not done in video presentation alone.

INFORMATION INTEGRATION IN THREE PHYSICAL DIMENSIONS

The author has created a physical, three-dimensional model of a hyperbolic paraboloid -- a quadric surface from high-school mathematics -- and applied self-adhesive captions to its surface. [6]

The steps in this process were as follows:

The author created geometry for the hyperbolic paraboloid using the ImplicitPlot3D package for Mathematica [2, 7]. ImplicitPlot3D creates triangular polygons after subdividing the space occupied by the mathematical function in three variables. The geometry of the implicit function evaluation was then saved to a file using the Mathematica ThreeScript standard package. [2]

A mathematically-generated hyperbolic paraboloid is a theoretical surface which is infinitesimally thin and cannot physically exist. Therefore, the geometry needed to be thickened. This was done using software written by the author. [8] This step also involved converting the ThreeScript file into Open Inventor file format and, ultimately the "STL" format, which is used by Rapid Prototyping machines.[9][5]

The finished CAD file was made physical in polymer resin by a stereolithography apparatus. [5] After this was done, the author, with the help of the Science Access Project at Oregon State University, created self-adhesive, embossed labels using the DotsPlus(tm) mathematical typesetting standard and a Tiger embossing printer.[10]

The hyperbolic paraboloid exercise demonstrates the basic principle of creating captions placed in 3-space which refer to mathematics in 3-D corresponding to the location that the captions appear. The author's hypothesis is that reading this object should be a spatially synergetic experience. However, the self-adhesive captions are not durable enough for a pedagogical object in daily classroom use.

IMPROVEMENTS TO THE CAD AND MANUFACTURING PROCESS

The indicated improvement to the idea of applying captions to a surface which describes mathematics or science is to create a 3-D CAD model of the DotsPlus Braille font, to compose the caption text and to apply it to the surface in CAD, then to build the surface with captions in one operation.

The author has created a set of three-dimensional CAD geometry to describe the DotsPlus(tm) standard font and has created a prototype system in the Alias|Wavefront Maya 3-D modeling software package for composing lines of DotsPlus(tm) Braille text from typed ASCII character strings. [11]

The author has demonstrated creating a 3-D prototype of an object containing modeled-in Braille text using Fused Deposition Modeling (FDM). [12] The object used in this demonstration, however, was a simple cylinder. In general, figures from Science and Mathematics are more complex than this. There remains work to be done to effectively integrate blocks of tactile text with free-form surfaces of arbitrary geometry.

CONCLUSION AND FUTURE WORK

Three application case studies have been presented which illustrate 'visualizing' mathematics in physical 3-D via computer-aided rapid prototyping technology, and applying tactile captions to mathematical models in 3-D.

At this juncture, we encounter some fundamental difficulties in matching CAD modeling techniques with Computer-Aided Rapid Prototyping and Manufacturing techniques in order to build a pipeline through which a scientific object can flow from design to a physical model for classroom use.

First, it can be seen that the scale of the geometry of a Braille dot is close to the limits of building resolution of some rapid prototyping devices, such as Fused Deposition Modeling (FDM). Some of the geometry in the CAD model test case was not rendered cleanly in the physical model. Other technologies, such as stereolithography, are known to have higher building accuracy, but due to other building requirements, such as additional supporting structure, dots can be lost in building and cleaning away the additional supports. These cases must typically be handled on an individual basis.

The author has demonstrated a method of mapping the X-Y-Z coordinate axes of a block of 3-D Braille text into the U-V-N coordinate space of a parametric surface, such as a NURBS surface.[13][14] This operation is similar in principle to the 'creep' Surface Operation (SOP) from Side Effects Software's 'prisms' and 'Houdini' modeling packages.[15]

The 'creep' operation produces the desired effect of applying text onto a free-form surface; however, it typically requires a parametric surface. The computer-aided rapid prototyping industry typically requires a "water-tight" 'STL' file, which contains nothing but triangle polygons. [5][9]

Rapid prototyping does not support parametric surfaces. It requires all triangles, tessellated from a parametric surface to share adjacent edges without exception, to form a "water-tight," closed surface model. This is typically not possible when tessellating parametric surfaces, because a model formed from multiple parametric surface patches will typically not be "stitched," "welded" or "water-tight" at the seams between the patches.

Polygon surface models originating from scientific visualization, geometric "iso-surfaces," [16] for example or 'implicit' surface evaluations [7] are typically unordered triangle meshes and not parametric surfaces.

Using the "winged-edge" model of polygon mesh representation, it is possible to navigate a polygonal surface from face-to-face topologically across the edges. [17] Via this method, one can draw lines on a polygon mesh which can delineate a rectangular 'parametric region' on the surface. One can then place a NURBS surface into this region and use it to map in the Braille text caption. This is the method the author proposes to employ to fully accomplish the stated task.

REFERENCES

[1] T.A. DeFanti and M.D. Brown, "Visualization in Scientific Computing," (chapter) Advances in Computers, Vol. 33, Academic Press, pp. 247-305, Spring 1991.

[2] Stephen Wolfram, "Mathematica, A System for doing Mathematics by Computer," The Mathematica Book, Third Edition, Wolfram Media, Inc. and Cambridge University Press, 1996, ISBN 0-521-58889-8; http://www.wolfram.com/.

[3] Stewart Dickson, 'Tactile Mathematics,' (chapter) Published in: "Mathematics and Art," Claude P. Bruter, Ed.; 2002: Springer-Verlag, Berlin. ISBN 3-540-43422-4. Proceedings of the International Colloquium on Art and Mathematics, Maubeuge, France, September 20-22, 2000.

[4] John M. Sullivan, George Francis and Stuart Levy, "The Optiverse," video 6 min. 35 sec. University of Illinois, 1998 http://new.math.uiuc.edu/optiverse/ Included in VideoMath-Festival at ICM '98; Hege, Polthier (Eds.) 1998 Video. 76 min., Berlin: Springer; ISBN 3-540-92633-X.

[5] Marshall Burns, Automated Fabrication: Improving Productivity in Manufacturing, Englewood Cliffs, NJ: Prentice Hall, 1993.

[6] Stewart Dickson, "Braille-Annotated Tactile Models In-The-Round of Three-Dimensional Mathematical Figures," http://emsh.calarts.edu/~mathart/Annotated_HyperPara.html.

[7] Steven Wilkinson, 3D Plots of Implicitly Defined Surfaces, http://library.wolfram.com/infocenter/MathSource/4189/.

[8] Stewart Dickson, "fromThreeScript," software to convert the output of Mathematica's ThreeScript package to OpenInventor format. "Thicken" software to add dimensional thickness to a single-sided polygon surface. "tostl" software to convert an Open Inventor file to STL format. http://emsh.calarts.edu/~mathart/sw/SPD_software.html http://emsh.calarts.edu/~mathart/sw/objView/fromThreeScript.html http://emsh.calarts.edu/~mathart/sw/objView/thicken.html.

[9] Marshall Burns, "The StL Format: Standard Data Format for Fabbers," http://www.ennex.com/fabbers/StL.asp.

[10] Mark Preddy, John Gardner, Steve Sahyun, and Dave Skrivanek Dotsplus: "How-To Make Tactile Figures And Tactile Formatted Math," Proceedings of the 1997 CSUN Conference on Technology and Persons with Disabilities, Los Angeles, CA, March 1997. http://dots.physics.orst.edu/publications/csun97dots.txt.

[11] Stewart Dickson, "DotsPlus 3-D for Maya," software for composing tactile Braille captions in Computer-Aided Design http://emsh.calarts.edu/~mathart/sw/DotsPlus/doc/DotsNew.html.

[12] Stewart Dickson, "Braille Typesetting in 3-D Computer-Aided Design and Manufacturing," http://emsh.calarts.edu/~mathart/Tactile_Math/DotsCAD.html.

[13] Stewart Dickson, "ParaMeshMap," software to 'map' X-Y-Z geometry onto a parametric surface. http://emsh.calarts.edu/~mathart/sw/objView/parameshmap.html.

[14] Les Piegl, Wayne Tiller; The NURBS Book; New York: Springer-Verlag, 1997; ISBN: 3-540-61545-8. http://www.springer-ny.com/detail.tpl?ISBN=3540615458.

[15] Side Effects Software, Inc. http://www.sidefx.com/.

[16] "Marching Cubes: A High Resolution 3D Surface Construction Algorithm," William E. Lorensen and Harvey E. Cline, Computer Graphics (Proceedings of SIGGRAPH '87), Vol. 21, No. 4, pp. 163-169.

[17] Andrew Glassner, "Maintaining Winged-Edge Models," Graphics Gems II, James Arvo, ed.; (IV.6 -- pp. 191-201) Academic Press, Inc.; ISBN: 0-12-064480-0.