THE UNIVERSITY OF CALGARY

Skeletal Design of Natural Forms

by

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A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF COMPUTER SCIENCE

CALGARY, ALBERTA

JANUARY, 1995

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a dissertation entitled ‘‘Skeletal Design of Natural Form’’ submitted by Jules Bloomenthal in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Date

Abstract

This dissertation is a presentation of methods for the design of geometric shapes that mimic many forms found in a natural environment. It is argued that a skeleton provides an intuitive and interactive specification for these geometric shapes, and that these shapes are well represented mathematically as implicit surfaces. Substantial portions of the dissertation are devoted to the development of techniques that relate the skeleton to the implicit surface, providing for a geometrically smooth result.

New techniques and presentations are given concerning convolution surfaces and conditions under which they are seamless and bulge-free. New techniques are also given to embed a volume within a surface. Models for the human hand and the botanical leaf illustrate the techniques.

Prior Publications and Collaborations

Certain techniques presented in this dissertation are extensions of work previously prepared by the author, alone or in collaboration with others.

The techniques for non-manifold polygonization, presented in chapter 4, resulted from a collaboration with Keith Ferguson, of this department. Although the work has not been previously published, a variation of the present treatment appears as a technical report of this department [Bloomenthal and Ferguson 1994].

Non-manifold polygonization developed from the author's attempt to trim a parametric surface against an implicitly defined volume. An *ad hoc* case analysis, briefly described in section 4.1, was nearly implemented when Keith Ferguson observed that a more elegant approach would be the generalization of conventional implicit surface definitions beyond their restriction to binary regions of space. He realized that a polygonizer predicated on multiple regions would produce the same vertices as with the case analysis. Together, we developed efficient and robust algorithms. Implementation was a shared and substantial undertaking that produced more than 3000 lines of software.

All other software implementations for the techniques described in this dissertation were developed by the author, with the exception of the RenderMan® renderer, developed by Pixar Corporation, an image filtering procedure used in parts of chapter 6, which had been previously implemented by Paul Heckbert, and the venation program for figure 5.2, which was jointly written with Andrew Glassner.

Some portions of chapter 3 were originally developed in a Xerox technical report [Bloomenthal 1989] and in [Bloomenthal 1988]; some other portions were derived from [Bloomenthal and Wyvill 1990] and still other portions were derived from [Bloomenthal 1994]. Figure 3.10 first appeared in [Bloomenthal 1994] and was originally suggested by Mark Ganter, who also provided the definition for the 'jacks' in chapter 3.

Portions of chapter 5 concerning convolution were co-developed with Ken Shoemake, and described in [Bloomenthal and Shoemake 1991]. Portions concerning ramification were partially derived from [Bloomenthal 1985], [Bloomenthal 1988], and [Bloomenthal 1989]. Portions concerning reference frames were partially derived from [Bloomenthal 1990]. Portions concerning texture coordinates were derived from [Bloomenthal 1989].

Portions of chapter 6 first appeared as an extended abstract in [Bloomenthal 1992].

Acknowledgements

It is my good fortune to have worked with many fine computer graphicists, and I would like to thank those who have helped make this dissertation possible.

I am indebted to Dennis Arnon, Chandrajit Bajaj, Tony DeRose, Robin Forrest, Mark Ganter, Pat Hanrahan, John Hart, Alyn Rockwood, Tom Sederberg, Joe Warren, Andy Witkin, and Geoff Wyvill for their clarifications of the intricate world of geometry. I thank them all for being so generous with their time.

I am grateful to my graduate committee. Brian Wyvill encouraged my return to school, and I deeply appreciate his many efforts as my supervisor. I warmly thank Przemek Prusinkiewicz for his enlightening conversation and many kindnesses. I thank Graham Birtwistle for his efforts to keep my American English. And I thank Marcia Perkins for providing her perspective as an artist. I am much indebted to Frank Crow for the direction and advice he offered while at PARC, and I am pleased he has offered the same as the external reviewer of this dissertation.

While at the University of Calgary, I enjoyed studying with Jon Rokne, departmental chair; his friendly conversation was much appreciated. My thanks to Brian Gaines and Ian Witten, who were of kind assistance as graduate advisers.

I am deeply indebted to many at Xerox PARC. Polle Zellweger was an understanding supervisor, and Kris Halvorsen and Mark Weiser provided additional managerial support. I thank Michael Plass for his generous assistance with Cedar, Jim Foote, Carl Hauser, Willie-Sue Orr, and Brent Welch for their system support, and Eric Bier, Ken Fishkin, Andrew Glassner, Ken Pier, Maureen Stone, Bridget Tracy, and Doug Wyatt for frequent miscellaneous assistance.

I bow to the hardware gods for their benevolence towards my much traveled Sun SparcStation, and I thank Jim D'Alfonso for his hardware support. I thank those many at PARC who developed the Cedar operating system, which provided a rich programming environment within which to implement the ideas described here and which made possible the fully electronic preparation of this dissertation.

I appreciate the understanding offered by Barbara Mones-Hattal and Alan Turransky as I completed this dissertation while teaching at George Mason University. Occasionally I found myself adrift at C, and I thank Paul Haeberli, Mark Hammel, and Paul Heckbert for their rescues.

When I discussed the difficulties of blending skeletally defined volumes with Ken Shoemake, he realized that convolution was appropriate and practical if its properties of separability and symmetry were exploited. I am much indebted to his insight and assistance.

Keith Ferguson suggested I generalize my approach to non-manifold polygonization, and together we developed an implementation. For his insight and indefatigable support, cheers!

Paul Heckbert offered a valuable critique of this dissertation. Many of his observations, notations, and suggestions appear in chapter 5, and he has provided numerous other suggestions to improve the readability of this dissertation. I am most grateful for his assistance.

All the best,

Jules Bloomenthal

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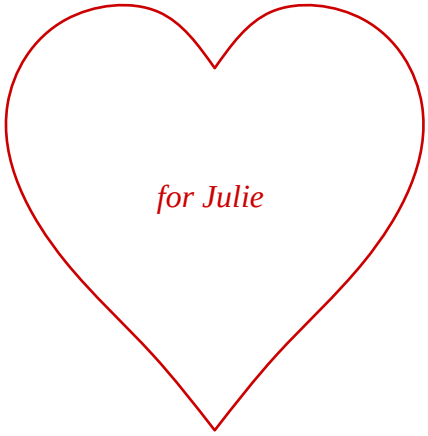
for Julie