Table of Contents

Approval Pag	e	ii
	`i	
Prior Publicat	ions and Collaborations	iv
	ements	
	Vi	
	tents	
	S	
Elst of Figure	20	
CHAPTER 1	INTRODUCTION	1
1.1	The Thesis	
1.2	Literature	
1.3	Organization	
1.3.1		
1.3.1	The Design of Shape	4
	Implicit Surfaces and Non-Manifold Surfaces	
1.3.3	Blends	
1.3.4	Examples	
1.4	Contributions	
1.5	Notes	7
		_
	SHAPE, DESIGN, AND THE SKELETON	8
2.1	A World of Form	
2.2	Structure from Form	
2.3	Form from Structure	13
2.4	The Skeleton	15
2.5	The Surface	17
2.6	Details, Details	
2.7	The Design Environment	
2.8	Animation	
2.9	Shape Taxonomy	28
2.10	Conclusions	
2.11	Notes	
2.11	110105	,_
CHAPTER 3	: IMPLICIT SURFACES 3	₹⊿
3.1	Introduction	
3.2	Solid Modeling	
3.2		
	Skeletal Design	
3.4	Visualization	
3.5	Polygonization	
3.5.1	Partitioning	
3.5.2	Root-Finding	
3.5.3	Cell Polygonization	17

3.5.4	Surface Bounds, Complexity, and Resolution	
3.6	Details, Details	
3.7	Interactivity	
3.8	Conclusions	. 57
3.9	Notes	. 57
CHAPTER 4	: NON-MANIFOLD SURFACES	60
4.1	Introduction	
4.2	Binary and Multiple Regions of Space	
4.3	Non-Manifold Representations in Solid Modeling	
4.4	Comparison with Conventional Polygonization	
4.4.1	Face Vertices	. 68
4.4.2	Multiple Edge Vertices	
4.4.3	Disjoint Lines and Surfaces	
4.4.3 4.4.4		
4.4.4	Complex Face Topologies	
	Intersection Curves	
4.5	Implementation	
4.5.1	Cell Propagation and Decomposition	. 12
4.5.2	Cell Polygonization	
4.5.2.1	Edge Vertex Calculation and Storage	. /4
4.5.2.2	Looped Edge Intersections	
4.5.2.3	Face Vertex Calculation	
4.5.2.4	Polygon Formation and Internal Vertices	. 79
4.5.3	Post Processes	
4.5.3.1	Thin or Small Triangles	. 80
4.5.3.2	Duplicated Vertices	
4.6	Calculation of Surface Normals	
4.7	Performance	
4.8	Examples	. 83
4.8.1	A Saucer and a Square	. 85
4.8.2	Sphere with Hole	. 86
4.8.3	Sphere and Plane with Hole	. 87
4.8.4	Blend to a Patch	. 88
4.9	Conclusions	. 91
4.10	Notes	. 92
CHAPTER 5	: VEIN ATTEMPTS	94
5.1	Summary	
5.2	Generalized Cylinders	9/1
5.3	Parametric Methods	
5.3.1	Reference Frames	
5.3.2	Cross-Sections	
5.3.3	Ramification	
5.3.3 5.4	Parametric Ramification	
J. 1	1 aramouro inamilio allon	102

	5.5	Implicit Ramification	106
	5.5.1	Distance Surfaces	
	5.5.2	Piecewise Approximations	108
	5.5.3	Distance Surfaces, Conclusion	110
	5.5.4	Blends	
	5.5.4.1	The Rolling Ball Blend	112
	5.5.4.2	Global Blends	
	5.5.4.3	Range-Controlled Blends	
	5.5.5	Bulges and the Combination Surface	110
	5.6	Convolution	121
		Convolution Blends	
	5.6.1		
	5.6.2	Superposition	123
	5.6.3	Evaluation	
	5.6.4	Arbitrary Position and Orientation	
	5.6.5	The Gaussian Integral	
	5.6.6	Normalizations	
	5.6.7	Convolution Surfaces	
	5.6.8	The Sinc Kernel	
	5.6.9	The B-spline and Wyvill Kernels	
	5.6.10	Separability, Revisited	
	5.6.11	Blend Control	
	5.6.12	Point Sources	143
	5.6.13	Cross-Sections, Revisited	145
	5.6.14	Ramification	146
	5.6.14.1	An Ad Hoc Method	
	5.6.14.2	Bulges	
	5.6.14.3	Bulge Reduction	
	5.6.14.4	Other Attempts	
	5.6.14.5	The Combination Surface	
	5.7	Texture Coordinates	
	5.8	Conclusions	
	5.9	Notes	
	5.7		102
(THAPTER 6.	HAND CRAFTING	165
•	6.1	Two Dimensional Skeletal Elements	
	6.2	Skeletal Contiguity, Cross-Sections, etc.	
	6.3	Articulation	
	6.4	Muscles and Arm	173
	6.5	The Hand	
	6.6	Convolution of Volumes	
	6.7		
		Unwanted Blending	
	6.8	Details, Details	
	6.9	Conclusions	
	6.10	Notes	182

CHAPTER 7	: ALIEN LEAF FORMS	184
7.1	The Leaf Skeleton	185
7.2	Blade Geometry	187
7.3	Of Blade and Vein	190
7.4	Texture	
7.5	Conclusions	193
7.6	Notes	194
CHAPTER 8	: CONCLUSIONS	197
REFERENCI	ES	200
		220
A.1	System Architecture	
A.2	An Implementation of the Convolution Surface	
A.3	An Implementation of Polygonal Convolution	230
A.4	Notes	231

List of Figures

2.1 2.2 2.3 2.4 2.5 2.6 2.7	A General Approach to Form from Structure A Skeleton and Possible Resulting Surfaces Different Integuments Hand and Sketched Skeletal Design Animation Categories Linear and Rotational Interpolation of Two Limbs Complex Metamorphoses
3.1	Interpolation of Sphere and Torus Functions
3.2	Implicit Interpolations
3.3	Ray-Traced Image
3.4	Contour Line Drawing
3.5	Surface Vertex Computation 46
3.6	Overview of a Polygonizer
3.7	Tetrahedral Cell Polygonization
3.8	Two Methods of Cell Polygonization
3.9	Two Polygon Formats
3.10	Torus R Us
3.11	Adaptively Sampled Trianguloid
3.12	A Sphere Partitioned with Differently Sized Cells
3.13 3.14	A Smooth Surface is Refined by Detail
3.14	Contour Discontinuities
3.13	Contour Discontinuities
4.1	Manifold and Non-Manifold Surfaces
4.2	A Natural Form Consisting of a Volume and a Surface 6
4.3	Possible Combinations of Vein and Blade
4.4	Polygonization and Ray-Tracing Sampling Rates
4.5	Combination of Surface and Volume
4.6	Partitioning of Surface and Volume 64
4.7	Possible Implicit Definitions 65
4.8	The Tessellation of a Non-Manifold 6.
4.9	Multiple Regions define the Sphere-Square
4.10	Need for Face Vertex
4.11	Alternatives to the Face Vertex
4.12 4.13	Need for Multiple Vertices along an Edge
4.13	Complex Face Topologies
4.14	Intersection Curves
4.16	The Five-Decomposition of a Cube
	The III Decomposition of a case

4.17	Sampled Points by Binary Subdivision	74
4.18	Two-Stage Edge Division for a Non-Manifold Polygonizer	
4.19	Loop Examples	75
4.20	Truncation of Large Loop	
4.21	Determining if a Face Contains only Disjoint Lines	77
4.22	Following a Face Contour	77
4.23	A Complex Face Topology	78
4.24	Face Contour Following using Directed Edges	
4.25	Polygon Formation	
4.26	Small and Thin Triangles	81
4.27	Need for Duplicated Vertices	
4.28	Saucer Shape	
4.29	Sphere/Hole	87
4.30	Definition for Sphere/Plane/Hole	87
4.31	Surfaces and Intersection Curves for Sphere/Plane/Hole	88
4.32	Determining a new (s, t)	88
4.33	Region Definition for Sphere/Patch	89
4.34	Line Drawings	
4.35	Shaded Images (with transparency)	90
F 1		0.5
5.1	A Generalized Cylinder	
5.2	An Organic Progression: Straight, Curved, and Tapered	95
5.3	Transforming a Cross-Section	
5.4	A Twisted Generalized Cylinder	
5.5	Severely Twisted Cross-Sections	97
5.6	The Frenet Frame	
5.7	Computing a Reference Frame from the Previous Frame	
5.8	Normal Vector along a Non-Planar Curve	
5.9	Position and Orientation of a Cross-Section	
5.10	Varying Cross-Sections	
5.11	A Generalized Cylinder	
5.12	Intersecting Cross-Sections	101
5.13	Branching Generalized Cylinder	102
5.14	Ramification of Cross-Sections	103
5.15	The Ramiform as a Lofted Surface	
5.16	Ramiform as a Sculptured Surface	
5.17	Distance to Curve	
5.18	Multiple Roots	108
5.19	Linear Approximation by Segments or Points	
5.20	Projecting a Point to a Line	109
5.21	Piecewise Linear Approximation	
5.22	Minimum Linear Distance	
5.23	The Rolling Ball Blend	113
5.24	Approximation to the Rolling Ball Blend	114

5.25	Average of Distances of 3-Segment Curve Approximation	115
5.26	The Elliptic Blend	116
5.27	The Super-Elliptic Blend	117
5.28	Super-Elliptic Blend of Sphere and Cylinder	118
5.29	Super-Elliptic Blend of Two Cylinders	
5.30	Convexity Measure	119
5.31	The Function h	
5.32	Two Perpendicular Segments	
5.33	Two Acute Segments	
5.34	More than Distance is Required for a Desired Blend	121
5.35	Terms for Two Blends	123
5.36	2D Filter Kernel, h(d)	
5.37	Sum of Weighted Kernels	
5.38	Infinite Sum is a Convolution	
5.39	The Superposition Property of Convolution	
5.40	The Delta Function	
5.41	Integrating the Kernel at Various Points	
5.42	An Illustration of Superposition	
5.43	Convolution of a Box Function	129
5.44	Lower-Dimensional Evaluation of the Convolution	
5.45	Two Segments Convolved with the Gaussian Kernel	
5.46	Rotated Segments	
5.47	Seven Segments	
5.48	The Sinc Kernel	
5.49	Convolution with Gaussian and Sinc	137
5.50	The Four Non-Zero Pieces of the Cubic B-Spline Kernel	
5.51	Rival Wyvill Filters	
5.52	Approximations to B-Spline Convolution	140
5.53	Approximations to Wyvill Convolution	
5.54	Comparison of Filter Kernels	
5.55	Domain of Integration Filter Scaled by 1.5 and 1.75	
5.56	End Contours	
5.57	Gaussian Convolution for Segments or Points	
5.58	Cross-Section Defined by an Image	
5.59	A Trifurcated Ramiform	147
5.60	A Two-Ramiform with Constant Radii	
5.61	Two Ramiform Skeletons	
5.62	A Tee Skeleton	
5.63	Contours for the Tee	
5.64	Tee Junction with Segment1 and Segment2 Touching	150
5.65	Tee Junction with Left Endpoint of Segment2 Moved	
5.66	Contours for the Tee with Shortened Segment2	
5.67	Tee Surface with Segment2 Shortened	
5.68	Animation of Tee to Cross	152

5.69 5.70 5.71 5.72 5.73 5.74 5.75 5.76 5.77	Two Methods of Tapered Junction View of Tee in XZ-Plane Union Surface and Convolution Surface Line Drawings of Combination Surface Combination Surface and Closeup Convexity Directions for Various Joint Configurations Texture Coordinates for Implicitly Defined Ramiform Modified Texture for an Implicitly Defined Ramiform An Envelope Curve	153 154 154 155 156 158 159
6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 6.13 6.14 6.15 6.16 6.17 6.18 6.19	Computation of f(p) Skeleton and Resulting Shape Effect of Image Resolution Overlapped and Contiguous Skeletons Surface Cross-Sections for Different Kernels Varying Polygon Width (Wyvill Kernel) Affect of Varying Polygon Width on Integration Filter A Smoothly Folding, Bulge-Free Form Improved Skeletal Fairness Seamlessness Individual Muscle and Parameters A Muscle An Arm Skeleton and Hand Individual and Combined Components Palm and Tendons Cross-Sections of Differently Dim. Skeletal Elements Skeletal Grouping Creased and Stretched Surfaces	168 169 170 170 171 171 172 173 174 176 177 178 179
7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 7.10 7.11 7.12 7.13 7.14	Petiole, Primary, and Secondary Veins Secondary Vein Branching from Primary Vein Five Patches Meet at a Point Leaf Venation Polygonal Web Polygonal Mesh Convex Polygon Triangulation Triangulated Blade Primary Veins in Isolation Cross-Section of Blade and a Vein Tee Blended into Blade Tee Filleted into Blade Alien Leaf Form Tertiary Venation	185 185 186 187 188 189 190 191 191 192 192

7.15	Leaf Margins	195
7.16	An Octree Node	195
A.1	Software Module Hierarchy	220
A.2	An Alternate View of Software Module Hierarchy	221
A.3	A Polygonal Skeletal Element	