David Salomon

Curves and Surfaces for Computer Graphics

With 207 Figures, 12 in Full Color



David Salomon (Emeritus)
Department of Computer Science
California State University, Northridge
Northridge, CA 91330-8281
U.S.A.
dsalomon@csun.edu

ISBN-10: 0-387-24196-5 e-ISBN: 0-387-28452-4 Printed on acid-free paper. ISBN-13: 978-0-387-24196-8

1521 (15. 576 6 567 21156 6

© 2006 Springer Science+Business Media, Inc.

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher (Springer Science+Business Media, Inc., 233 Spring St., New York, NY 10013, USA), except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden.

The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

Printed in the United States of America. (HAM)

9 8 7 6 5 4 3 2 1 SPIN 11360285

springeronline.com

Contents

	Prefa	nce		
1	Basic Theory			1
	1.1	Points and Vectors	1	
	1.2	Parametric Blending	10	
	1.3	Parametric Curves	11	
	1.4	Properties of Parametric Curves	13	
	1.5	PC Curves	18	
	1.6	Curvature and Torsion	26	
	1.7	Special and Degenerate Curves	35	
	1.8	Basic Concepts of Surfaces	35	
	1.9	The Cartesian Product	38	
	1.10	Connecting Surface Patches	40	
	1.11	Fast Computation of a Bicubic Patch	41	
	1.12	Subdividing a Surface Patch	43	
	1.13	Surface Normals	46	
2	Linear Interpolation			49
	2.1	Straight Segments	49	
	2.2	Polygonal Surfaces	53	
	2.3	Bilinear Surfaces	59	
	2.4	Lofted Surfaces	64	
3	Polynomial Interpolation			71
	3.1	Four Points	72	
	3.2	The Lagrange Polynomial	76	
	3.3	The Newton Polynomial	85	
	3.4	Polynomial Surfaces	87	
	3.5	The Biquadratic Surface Patch	87	
	3.6	The Bicubic Surface Patch	89	
	3.7	Coons Surfaces	93	
	3.8	Gordon Surfaces	108	

xiv Contents

4	Hermi	te Interpolation		11	
	4.1	Interactive Control	112		
	4.2	The Hermite Curve Segment	113		
	4.3	Degree-5 Hermite Interpolation	122		
	4.4	Controlling the Hermite Segment	123		
	4.5	Truncating and Segmenting	127		
	4.6	Hermite Straight Segments	129		
	4.7	A Variant Hermite Segment	131		
	4.8	Ferguson Surfaces	132		
	4.9	Bicubic Hermite Patch	134		
	4.10	Biquadratic Hermite Patch	137		
5	Spline Interpolation				
	5.1	The Cubic Spline Curve	141		
	5.2	The Quadratic Spline	156		
	5.3	The Quintic Spline	158		
	5.4	Cardinal Splines	161		
	5.5	Catmull–Rom Surfaces	165		
	5.6	Kochanek-Bartels Splines	167		
6	Bézier	Approximation		17	
	6.1	The Bézier Curve	176		
	6.2	The Bernstein Form of the Bézier Curve	178		
	6.3	Fast Calculation of the Curve	185		
	6.4	Properties of the Curve	190		
	6.5	Connecting Bézier Curves	192		
	6.6	The Bézier Curve as a Linear Interpolation	194		
	6.7	Blossoming	198		
	6.8	Subdividing the Bézier Curve	202		
	6.9	Degree Elevation	205		
	6.10	Reparametrizing the Curve	207		
	6.11	Cubic Bézier Segments with Tension	210		
	6.12	An Interpolating Bézier Curve: I	212		
	6.13	An Interpolating Bézier Curve: II	214		
	6.14	Nonparametric Bézier Curves	217		
	6.15	Rational Bézier Curves	217		
	6.16	Rectangular Bézier Surfaces	219		
	6.17	Subdividing Rectangular Patches	224		
	6.18	Degree Elevation	225		
	6.19	Nonparametric Rectangular Patches	227		
	6.20	Joining Rectangular Bézier Patches	228		
	6.21	An Interpolating Bézier Surface Patch	230		
	6.22	Rational Bézier Surfaces	232		
	6.23	Triangular Bézier Surfaces	234		
	6.24	Joining Triangular Bézier Patches	242		
	6.25	Reparametrizing the Bézier Surface	246		
	6.26	The Gregory Patch	248		

Contents xv

7	B-Spli	ne Approximation		
	7.1	The Quadratic Uniform B-Spline	252	
	7.2	The Cubic Uniform B-Spline	256	
	7.3	Multiple Control Points	263	
	7.4	Cubic B-Splines with Tension	265	
	7.5	Cubic B-Spline and Bézier Curves	268	
	7.6	Higher-Degree Uniform B-Splines	268	
	7.7	Interpolating B-Splines	270	
	7.8	A Knot Vector-Based Approach	271	
	7.9	Recursive Definitions of the B-Spline	280	
	7.10	Open Uniform B-Splines	281	
	7.11	Nonuniform B-Splines	286	
	7.12	Matrix Form of the Nonuniform B-Spline	295	
	7.13	Subdividing the B-spline Curve	299	
	7.14	Nonuniform Rational B-Splines (NURBS)	302	
	7.15	Uniform B-Spline Surfaces	308	
	7.16	Relation to Other Surfaces	312	
	7.17	An Interpolating Bicubic Patch	315	
	7.18	The Quadratic-Cubic B-Spline Surface	317	
,	Subdivision Methods			
	8.1	Introduction	319	
	8.2	Chaikin's Refinement Method	319	
	8.3	Quadratic Uniform B-Spline by Subdivision	325	
	8.4	Cubic Uniform B-Spline by Subdivision	327	
	8.5	Biquadratic B-Spline Surface by Subdivision	331	
	8.6	Bicubic B-Spline Surface by Subdivision	336	
	8.7	Polygonal Surfaces by Subdivision	341	
	8.8	Doo Sabin Surfaces	341	
	8.9	Catmull-Clark Surfaces	343	
	8.10	Loop Surfaces	344	
	Sweep Surfaces			
	9.1	Sweep Surfaces	348	
	9.2	Surfaces of Revolution	353	
	9.3	An Alternative Approach	355	
	9.4	Skinned Surfaces	360	
_	Conic	Sections		
3	Approximate Circles			
	B.1	Circles and Bézier Curves	369	
	B.2	The Cubic B-Spline as a Circle	373	
C	Graph	ics Gallery		
)	Mathe	ematica Notes		
	Δηςυν	ers to Evergises		

xvi	Contents

Bibliography _	447
Index	45 I

My kind publishers announced, some time ago, a table of contents, which included chapters on jay and fish-hawk, panther, and musquash, and a certain savage old bull moose that once took up his abode too near my camp for comfort. My only excuse for their non-appearance is that my little book was full before their turn came. They will find their place, I trust, in another volume presently.

—William J. Long, Secret of the Woods (1901)