

- List of Figures p. xxi
- List of Tables p. xxv
- Preface p. xxvii
- Chapter 1 Introduction p. 1
- 1.1 A Brief Motivation p. 1
- 1.2 A Summary of the Chapters p. 3
- 1.3 Text Is Not Enough p. 5
- Chapter 2 Geometrical Methods p. 7
- 2.1 Transformations p. 8
- 2.1.1 Scaling p. 8
- 2.1.2 Rotation p. 8
- 2.1.3 Translation p. 9
- 2.1.4 Homogeneous Transformations p. 9
- 2.2 Coordinate Systems p. 10
- 2.3 Quaternions p. 11
- 2.3.1 Quaternion Algebra p. 11
- 2.3.2 Relationship of Quaternions to Rotations p. 13
- 2.3.3 Conversion between Angle-Axis and Rotation Matrix p. 15
- 2.3.4 Conversion between Quaternion and Angle-Axis p. 16
- 2.3.5 Conversion between Quaternion and Rotation Matrix p. 17
- 2.4 Euler Angles p. 18
- 2.4.1 Factoring Rotation Matrices p. 19
- 2.4.2 Factor Product of Two p. 24
- 2.5 Standard 3D Objects p. 26
- 2.5.1 Spheres p. 26
- 2.5.2 Oriented Boxes p. 29
- 2.5.3 Capsules p. 32
- 2.5.4 Lozenges p. 34
- 2.5.5 Cylinders p. 35
- 2.5.6 Ellipsoids p. 36
- 2.6 Distance Methods p. 38
- 2.6.1 Point to Linear Component p. 38
- 2.6.2 Linear Component to Linear Component p. 41
- 2.6.3 Point to Triangle p. 49
- 2.6.4 Linear Component to Triangle p. 53
- 2.6.5 Point to Rectangle p. 57
- 2.6.6 Linear Component to Rectangle p. 58
- 2.6.7 Triangle to Triangle p. 61
- 2.6.8 Triangle to Rectangle p. 61
- 2.6.9 Rectangle to Rectangle p. 61
- 2.6.10 Point to Oriented Box p. 61
- 2.6.11 Miscellaneous p. 65
- Chapter 3 The Graphics Pipeline p. 79
- 3.1 Model and World Coordinates p. 80

- 3.2 Perspective Projection p. 80
- 3.2.1 Lines Project to Lines p. 81
- 3.2.2 Triangles Project to Triangles p. 83
- 3.2.3 Conics Project to Conics p. 83
- 3.3 Camera Models p. 84
- 3.3.1 Standard Camera Model p. 85
- 3.3.2 General Camera Model p. 87
- 3.3.3 Model-to-View Transformation p. 87
- 3.3.4 Mapping to Screen Coordinates p. 89
- 3.3.5 Screen Space Distance Measurements p. 90
- 3.4 Culling and Clipping p. 91
- 3.4.1 Object Culling p. 92
- 3.4.2 Back Face Culling p. 92
- 3.4.3 Clipping p. 93
- 3.5 Surface and Vertex Attributes p. 99
- 3.5.1 Depth p. 99
- 3.5.2 Colors p. 99
- 3.5.3 Lighting and Materials p. 100
- 3.5.4 Textures p. 105
- 3.5.5 Transparency and Opacity p. 108
- 3.5.6 Fog p. 109
- 3.5.7 Combining Attributes p. 110
- 3.6 Rasterizing p. 113
- 3.6.1 Lines p. 113
- 3.6.2 Circles p. 117
- 3.6.3 Ellipses p. 119
- 3.6.4 Triangles p. 124
- 3.6.5 Interpolation during Rasterization p. 126
- 3.7 An Efficient Clipping and Lighting Pipeline p. 132
- 3.7.1 Triangle Meshes p. 132
- 3.7.2 Clipping a Triangle Mesh p. 133
- 3.7.3 Computing Vertex Attributes p. 136
- 3.8 Issues of Software, Hardware, and APIs p. 138
- Chapter 4 Hierarchical Scene Representations p. 141
- 4.1 Tree-Based Representation p. 143
- 4.1.1 Transforms p. 144
- 4.1.2 Bounding Volumes p. 145
- 4.1.3 Renderer State p. 146
- 4.1.4 Animation p. 147
- 4.2 Updating a Scene Graph p. 147
- 4.2.1 Merging Two Spheres p. 148
- 4.2.2 Merging Two Oriented Boxes p. 149
- 4.2.3 Merging Two Capsules p. 151
- 4.2.4 Merging Two Lozenges p. 151

- 4.2.5 Merging Two Cylinders p. 152
- 4.2.6 Merging Two Ellipsoids p. 152
- 4.2.7 Algorithm for Scene Graph Updating p. 152
- 4.3 Rendering a Scene Graph p. 157
- 4.3.1 Culling by Spheres p. 157
- 4.3.2 Culling by Oriented Boes p. 159
- 4.3.3 Culling by Capsules p. 160
- 4.3.4 Culling by Lozenges p. 161
- 4.3.5 Culling by Cylinders p. 163
- 4.3.6 Culling by Ellipsoids p. 164
- 4.3.7 Algorithm for Scene Graph Rendering p. 166
- Chapter 5 Picking p. 169
- 5.1 Intersection of a Linear Component and a Sphere p. 171
- 5.2 Intersection of a Linear Component and a Box p. 172
- 5.2.1 Line Segment p. 176
- 5.2.2 Ray p. 177
- 5.2.3 Line p. 179
- 5.3 Intersection of a Linear Component and a Capsule p. 179
- 5.4 Intersection of a Linear Component and a Lozenge p. 180
- 5.5 Intersection of a Linear Component and a Cylinder p. 181
- 5.6 Intersection of a Linear Component and an Ellipsoid p. 182
- 5.7 Intersection of a Linear Component and a Triangle p. 182
- Chapter 6 Collision Detection p. 185
- 6.1 Design Issues p. 186
- 6.2 Intersection of Dynamic Objects and Lines p. 188
- 6.2.1 Spheres p. 188
- 6.2.2 Oriented Boxes p. 190
- 6.2.3 Capsules p. 190
- 6.2.4 Lozenges p. 191
- 6.2.5 Cylinders p. 191
- 6.2.6 Ellipsoids p. 191
- 6.2.7 Triangles p. 192
- 6.3 Intersection of Dynamic Objects and Planes p. 193
- 6.3.1 Spheres p. 193
- 6.3.2 Oriented Boxes p. 194
- 6.3.3 Capsules p. 196
- 6.3.4 Lozenges p. 197
- 6.3.5 Cylinders p. 198
- 6.3.6 Ellipsoids p. 201
- 6.3.7 Triangles p. 202
- 6.4 Static Object-Object Intersection p. 203
- 6.4.1 Spheres, Capsules, and Lozenges p. 204
- 6.4.2 Oriented Boxes p. 205
- 6.4.3 Oriented Boxes and Triangles p. 207

- 6.4.4 Triangles p. 210
- 6.5 Dynamic Object-Object Intersection p. 214
- 6.5.1 Spheres, Capsules, and Lozenges p. 215
- 6.5.2 Oriented Boxes p. 217
- 6.5.3 Oriented Boxes and Triangles p. 223
- 6.5.4 Triangles p. 232
- 6.6 Oriented Bounding Box Trees p. 244
- 6.7 Processing of Rotating and Moving Objects p. 245
- 6.7.1 Equations of Motion p. 246
- 6.7.2 Closed-Form Algorithm p. 248
- 6.7.3 Algorithm Based on a Numerical Ordinary Differential Equation Solver p. 249
- 6.8 Constructing an Obb Tree p. 250
- 6.9 A Simple Dynamic Collision Detection System p. 251
- 6.9.1 Testing for Collision p. 252
- 6.9.2 Finding Collision Points p. 253
- Chapter 7 Curves p. 257
- 7.1 Definitions p. 258
- 7.2 Reparameterization by Arc Length p. 260
- 7.3 Special Curves p. 261
- 7.3.1 Bezier Curves p. 261
- 7.3.2 Natural, Clamped, and Closed Cubic Splines p. 264
- 7.3.3 Nonparametric B-Spline Curves p. 267
- 7.3.4 Kochanek-Bartels Splines p. 271
- 7.4 Subdivision p. 276
- 7.4.1 Subdivision by Uniform Sampling p. 276
- 7.4.2 Subdivision by Arc Length p. 276
- 7.4.3 Subdivision by Midpoint Distance p. 277
- 7.4.4 Subdivision by Variation p. 278
- 7.4.5 Subdivision by Minimizing Variation p. 282
- 7.4.6 Fast Subdivision for Cubic Curves p. 283
- 7.5 Orientation of Objects on Curved Paths p. 285
- 7.5.1 Orientation Using the Frenet Frame p. 285
- 7.5.2 Orientation Using a Fixed "Up" Vector p. 286
- Chapter 8 Surfaces p. 287
- 8.1 Definitions p. 288
- 8.2 Curvature p. 289
- 8.2.1 Curvatures for Parametric Surfaces p. 289
- 8.2.2 Curvatures for Implicit Surfaces p. 290
- 8.2.3 Curvatures for Graphs p. 293
- 8.3 Special Surfaces p. 293
- 8.3.1 Bezier Rectangle Patches p. 293
- 8.3.2 Bezier Triangle Patches p. 297
- 8.3.3 Bezier Cylinder Surfaces p. 301
- 8.3.4 Nonparametric B-Spline Rectangle Patches p. 302

- 8.3.5 Quadric Surfaces p. 304
- 8.3.6 Tube Surfaces p. 306
- 8.4 Subdivision p. 306
- 8.4.1 Subdivision of Bezier Rectangle Patches p. 306
- 8.4.2 Subdivision of Bezier Triangle Patches p. 321
- 8.4.3 Subdivision of Bezier Cylinder Surfaces p. 328
- 8.4.4 Subdivision of Spheres and Ellipsoids p. 328
- 8.4.5 Subdivision of Tube Surfaces p. 339
- Chapter 9 Animation of Characters p. 341
- 9.1 Key Frame Animation p. 342
- 9.1.1 Quaternion Calculus p. 342
- 9.1.2 Spherical Linear Interpolation p. 343
- 9.1.3 Spherical Cubic Interpolation p. 345
- 9.1.4 Spline Interpolation of Quaternions p. 346
- 9.1.5 Updating a Key Frame Node p. 347
- 9.2 Inverse Kinematics p. 348
- 9.2.1 Numerical Solution by Jacobian Methods p. 350
- 9.2.2 Numerical Solution by Nonlinear Optimization p. 351
- 9.2.3 Numerical Solution by Cyclic Coordinate Descent p. 351
- 9.3 Skinning p. 356
- Chapter 10 Geometric Level of Detail p. 359
- 10.1 Sprites and Billboards p. 360
- 10.2 Discrete Level of Detail p. 361
- 10.3 Continuous Level of Detail p. 362
- 10.3.1 Simplification Using Quadric Error Metrics p. 362
- 10.3.2 The Algorithm p. 364
- 10.3.3 Construction of the Error Metric p. 365
- 10.3.4 Simplification at Run Time p. 365
- 10.3.5 Selecting Surface Attributes p. 366
- Chapter 11 Terrain p. 369
- 11.1 Terrain Topology p. 370
- 11.2 Vertex-Based Simplification p. 373
- 11.2.1 Distant Terrain Assumption p. 373
- 11.2.2 Close Terrain Assumption p. 374
- 11.2.3 No Assumption p. 375
- 11.3 Block-Based Simplification p. 375
- 11.3.1 Distant Terrain Assumption p. 376
- 11.3.2 Close Terrain Assumption p. 378
- 11.3.3 No Assumption p. 379
- 11.4 Vertex Dependencies p. 381
- 11.5 Block Rendering p. 383
- 11.6 The Full Algorithm p. 385
- 11.7 Other Issues p. 392
- 11.7.1 Terrain Pages and Memory Management p. 392

- 11.7.2 Vertex Attributes p. 395
- 11.7.3 Height Calculations p. 397
- 11.8 Height Fields from Point Sets or Triangle Meshes p. 398
- 11.8.1 Linear Interpolation p. 398
- 11.8.2 Quadratic Interpolation p. 399
- Chapter 12 Spatial Sorting p. 411
- 12.1 Quadrees and Octrees p. 412
- 12.2 Portals p. 413
- 12.3 Binary Space Partitioning p. 417
- 12.3.1 BSP Tree Construction p. 418
- 12.3.2 Hidden Surface Removal p. 420
- 12.3.3 Visibility Determination p. 424
- 12.3.4 Picking and Collision Detection p. 425
- Chapter 13 Special Effects p. 427
- 13.1 Lens Flare p. 427
- 13.2 Environment Mapping p. 428
- 13.3 Bump Mapping p. 429
- 13.4 Volumetric Fogging p. 430
- 13.5 Projected Lights p. 430
- 13.6 Projected Shadows p. 431
- 13.7 Particle Systems p. 432
- 13.8 Morphing p. 433
- Appendix A Object-Oriented Infrastructure p. 435
- A.1 Object-Oriented Software Construction p. 435
- A.1.1 Software Quality p. 436
- A.1.2 Modularity p. 437
- A.1.3 Reusability p. 439
- A.1.4 Functions and Data p. 440
- A.1.5 Object Orientation p. 441
- A.2 Style, Naming Conventions, and Namespaces p. 442
- A.3 Run-Time Type Information p. 444
- A.3.1 Single-Inheritance Systems p. 444
- A.3.2 Multiple-Inheritance Systems p. 447
- A.3.3 Macro Support p. 450
- A.4 Templates p. 451
- A.5 Shared Objects and Reference Counting p. 453
- A.6 Streaming p. 459
- A.6.1 Saving Data p. 459
- A.6.2 Loading Data p. 460
- A.6.3 Streaming Support p. 461
- A.7 Startup and Shutdown p. 464
- Appendix B Numerical Methods p. 469
- B.1 Systems of Equations p. 469
- B.1.1 Linear Systems p. 469

- B.1.2 Polynomial Systems p. 470
- B.2 Eigensystems p. 472
- B.3 Least-Squares Fitting p. 472
- B.3.1 Linear Fitting of Points $(x, f(x))$ p. 472
- B.3.2 Linear Fitting of Points Using Orthogonal Regression p. 473
- B.3.3 Planar Fitting of Points $(x, y, f(x, y))$ p. 474
- B.3.4 Hyperplanar Fitting of Points Using Orthogonal Regression p. 475
- B.3.5 Fitting a Circle to 2D Points p. 476
- B.3.6 Fitting a Sphere to 3D Points p. 478
- B.3.7 Fitting a Quadratic Curve to 2D Points p. 480
- B.3.8 Fitting a Quadric Surface to 3D Points p. 481
- B.4 Minimization p. 481
- B.4.1 Methods in One Dimension p. 481
- B.4.2 Methods in Many Dimensions p. 482
- B.5 Root Finding p. 485
- B.5.1 Methods in One Dimension p. 485
- B.5.2 Methods in Many Dimensions p. 489
- B.6 Integration p. 491
- B.6.1 Romberg Integration p. 491
- B.6.2 Gaussian Quadrature p. 495
- B.7 Differential Equations p. 496
- B.7.1 Ordinary Differential Equations p. 496
- B.7.2 Partial Differential Equations p. 499
- B.8 Fast Function Evaluation p. 503
- B.8.1 Square Root and Inverse Square Root p. 503
- B.8.2 Sine, Cosine, and Tangent p. 504
- B.8.3 Inverse Tangent p. 505
- B.8.4 CORDIC Methods p. 507
- Glossary p. 509
- Bibliography p. 521
- Index p. 527
- About the Author p. 557
- About the CD-ROM p. 559
- Trademarks p. 561