

Contents

Preface	xiii
About the Author	xvii

CHAPTER 1 Introduction	1
1.1 Motion perception.....	2
1.2 The heritage of animation	4
1.2.1 Early devices.....	4
1.2.2 The early days of “conventional” animation	6
1.2.3 Disney	7
1.2.4 Contributions of others	8
1.2.5 Other media for animation	8
1.3 Animation production.....	9
1.3.1 Principles of animation.....	10
1.3.2 Principles of filmmaking	12
1.3.3 Sound	14
1.4 Computer animation production.....	15
1.4.1 Computer animation production tasks	16
1.4.2 Digital editing	18
1.4.3 Digital video	20
1.4.4 Digital audio	21
1.5 A brief history of computer animation	22
1.5.1 Early activity (pre-1980)	22
1.5.2 The middle years (the 1980s).....	25
1.5.3 Animation comes of age (the mid-1980s and beyond)	26
1.6 Summary	29

CHAPTER 2 Technical Background.....	33
2.1 Spaces and transformations	33
2.1.1 The display pipeline	34
2.1.2 Homogeneous coordinates and the transformation matrix	38
2.1.3 Concatenating transformations: multiplying transformation matrices	40
2.1.4 Basic transformations	40
2.1.5 Representing an arbitrary orientation.....	42
2.1.6 Extracting transformations from a matrix.....	46
2.1.7 Description of transformations in the display pipeline.....	47
2.1.8 Error considerations.....	48

2.2	Orientation representation	52
2.2.1	Fixed-angle representation	54
2.2.2	Euler angle representation	56
2.2.3	Angle and axis representation	57
2.2.4	Quaternion representation.....	58
2.2.5	Exponential map representation	60
2.3	Summary	60
CHAPTER 3	Interpolating Values	61
3.1	Interpolation	61
3.1.1	The appropriate function	62
3.1.2	Summary	65
3.2	Controlling the motion of a point along a curve	65
3.2.1	Computing arc length	66
3.2.2	Speed control	78
3.2.3	Ease-in/ease-out	80
3.2.4	General distance-time functions	86
3.2.5	Curve fitting to position-time pairs.....	90
3.3	Interpolation of orientations	91
3.3.1	Interpolating quaternions	91
3.4	Working with paths	96
3.4.1	Path following.....	96
3.4.2	Orientation along a path	96
3.4.3	Smoothing a path.....	100
3.4.4	Determining a path along a surface	106
3.4.5	Path finding.....	108
3.5	Chapter summary.....	108
CHAPTER 4	Interpolation-Based Animation	111
4.1	Key-frame systems	111
4.2	Animation languages	115
4.2.1	Artist-oriented animation languages	116
4.2.2	Full-featured programming languages for animation	116
4.2.3	Articulation variables	117
4.2.4	Graphical languages	117
4.2.5	Actor-based animation languages	118
4.3	Deforming objects	119
4.3.1	Picking and pulling.....	119
4.3.2	Deforming an embedding space.....	121

4.4	Three-dimensional shape interpolation	135
4.4.1	Matching topology	136
4.4.2	Star-shaped polyhedra	137
4.4.3	Axial slices	137
4.4.4	Map to sphere	139
4.4.5	Recursive subdivision	145
4.5	Morphing (two-dimensional)	147
4.5.1	Coordinate grid approach	147
4.5.2	Feature-based morphing	153
4.6	Chapter summary	159
CHAPTER 5	Kinematic Linkages	161
5.1	Hierarchical modeling	162
5.1.1	Data structure for hierarchical modeling	164
5.1.2	Local coordinate frames	170
5.2	Forward kinematics	171
5.3	Inverse kinematics	172
5.3.1	Solving a simple system by analysis	173
5.3.2	The Jacobian	174
5.3.3	Numeric solutions to IK	178
5.3.4	Summary	185
5.4	Chapter summary	185
CHAPTER 6	Motion Capture	187
6.1	Motion capture technologies	187
6.2	Processing the images	188
6.3	Camera calibration	190
6.4	Three-dimensional position reconstruction	191
6.4.1	Multiple markers	192
6.4.2	Multiple cameras	192
6.5	Fitting to the skeleton	193
6.6	Output from motion capture systems	195
6.7	Manipulating motion capture data	196
6.7.1	Processing the signals	196
6.7.2	Retargeting the motion	197
6.7.3	Combining motions	197
6.8	Chapter summary	198
CHAPTER 7	Physically Based Animation	199
7.1	Basic physics—a review	200
7.1.1	Spring-damper pair	202

7.2	Spring animation examples	202
7.2.1	Flexible objects.....	202
7.2.2	Virtual springs	205
7.3	Particle systems	205
7.3.1	Particle generation	206
7.3.2	Particle attributes	207
7.3.3	Particle termination	207
7.3.4	Particle animation.....	207
7.3.5	Particle rendering.....	207
7.3.6	Particle system representation.....	208
7.3.7	Forces on particles.....	208
7.3.8	Particle life span	209
7.4	Rigid body simulation	209
7.4.1	Bodies in free fall	210
7.4.2	Bodies in collision	219
7.4.3	Dynamics of linked hierarchies.....	232
7.5	Cloth.....	235
7.5.1	Direct modeling of folds	237
7.5.2	Physically based modeling	240
7.6	Enforcing soft and hard constraints	244
7.6.1	Energy minimization	244
7.6.2	Space-time constraints.....	247
7.7	Chapter summary.....	249
CHAPTER 8	Fluids: Liquids and Gases	251
8.1	Specific fluid models.....	251
8.1.1	Models of water.....	251
8.1.2	Modeling and animating clouds	262
8.1.3	Modeling and animating fire	268
8.1.4	Summary	270
8.2	Computational fluid dynamics	270
8.2.1	General approaches to modeling fluids.....	271
8.2.2	CFD equations	272
8.2.3	Grid-based approach.....	276
8.2.4	Particle-based approaches including smoothed particle hydrodynamics	277
8.3	Chapter summary.....	280
CHAPTER 9	Modeling and Animating Human Figures	283
9.1	Overview of virtual human representation	283
9.1.1	Representing body geometry.....	284
9.1.2	Geometry data acquisition.....	285

9.1.3 Geometry deformation.....	286
9.1.4 Surface detail	286
9.1.5 Layered approach to human figure modeling.....	287
9.2 Reaching and grasping	290
9.2.1 Modeling the arm	290
9.2.2 The shoulder joint.....	293
9.2.3 The hand	293
9.2.4 Coordinated movement.....	295
9.2.5 Reaching around obstacles	296
9.2.6 Strength.....	297
9.3 Walking.....	298
9.3.1 The mechanics of locomotion	298
9.3.2 The kinematics of the walk	303
9.3.3 Using dynamics to help produce realistic motion	303
9.3.4 Forward dynamic control	308
9.3.5 Summary	308
9.4 Coverings	309
9.4.1 Clothing	309
9.4.4 Hair	309
9.5 Chapter summary.....	311
CHAPTER 10 Facial Animation	317
10.1 The human face	317
10.1.1 Anatomic structure	317
10.1.2 The facial action coding system.....	319
10.2 Facial models.....	320
10.2.1 Creating a continuous surface model.....	322
10.2.2 Textures	325
10.3 Animating the face	327
10.3.1 Parameterized models.....	327
10.3.2 Blend shapes	327
10.3.3 Muscle models.....	329
10.3.4 Expressions	332
10.3.5 Summary	332
10.4 Lip-sync animation	333
10.4.1 Articulators of speech.....	333
10.4.2 Phonemes	334
10.4.3 Coarticulation.....	335
10.4.4 Prosody	335
10.5 Chapter summary.....	335

CHAPTER 11 Behavioral Animation	339
11.1 Primitive behaviors.....	342
11.1.1 Flocking behavior	342
11.1.2 Prey–predator behavior.....	351
11.2 Knowledge of the environment.....	352
11.2.1 Vision	352
11.2.2 Memory.....	353
11.3 Modeling intelligent behavior	354
11.3.1 Autonomous behavior.....	354
11.3.2 Expressions and gestures	356
11.3.3 Modeling individuality: personality and emotions	357
11.4 Crowds	358
11.4.1 Crowd behaviors	359
11.4.2 Internal structure	359
11.4.3 Crowd control	360
11.4.4 Managing n -squared complexity	360
11.4.5 Appearance	361
11.5 Chapter summary.....	361
CHAPTER 12 Special Models for Animation	365
12.1 Implicit surfaces	365
12.1.1 Basic implicit surface formulation	365
12.1.2 Animation using implicitly defined objects.....	367
12.1.3 Collision detection.....	368
12.1.4 Deforming the implicit surface as a result of collision	368
12.1.5 Level set methods	371
12.1.6 Summary	372
12.2 Plants.....	372
12.2.1 A little bit of botany	372
12.2.2 L-systems	374
12.2.3 Animating plant growth.....	379
12.2.4 Summary	381
12.3 Subdivision surfaces	382
12.4 Chapter summary.....	384
Appendix A Rendering Issues	387
Appendix B Background Information and Techniques.....	407
Index	503