

Contents

Contributors	xiii
About the Editors	xvii
Preface	xix

PART 1 THEORY AND METHODS

CHAPTER 1	Skeletonization and its applications – a review .	3
	Punam K. Saha, Gunilla Borgefors, and Gabriella Sanniti di Baja	
1.1	Introduction	3
1.1.1	Basic Concepts	3
1.1.2	Background	5
1.2	Different Approaches of Skeletonization	7
1.2.1	Geometric Approaches	10
1.2.2	Curve Propagation Approaches	11
1.2.3	Digital Approaches	13
1.3	Topology Preservation	19
1.4	Pruning	22
1.5	Multiscale Skeletonization	23
1.6	Parallelization	24
1.6.1	Subiterative Parallelization Schemes	25
1.6.2	Parallelization Using Minimal Nonsimple Sets	25
1.6.3	Parallelization Using P-Simple Points	26
1.7	Applications	26
1.8	Performance Evaluation	29
1.9	Conclusions	30
	References	31
CHAPTER 2	Multiscale 2D medial axes and 3D surface skeletons by the image foresting transform	43
	Alexandre Falcão, Cong Feng, Jacek Kustra, and Alexandru Telea	
2.1	Introduction	43
2.2	Related Work	44
2.2.1	Definitions	45
2.2.2	Skeleton Regularization	45
2.3	Proposed Method	48
2.3.1	Multiscale Regularization—Strengths and Weaknesses	49

2.3.2	Image Foresting Transform	50
2.3.3	Multiscale Skeletonization—Putting It All Together	56
2.4	Comparative Analysis	60
2.4.1	2D Medial Axes	60
2.4.2	3D Medial Surfaces	60
2.5	Conclusion	67
	References	67
TER 3	Fuzzy skeleton and skeleton by influence zones — a review	71
	Isabelle Bloch	
3.1	Introduction	71
3.2	Distance-Based Approaches	73
3.3	Morphological Approaches to Compute the Centers of Maximal Balls	75
3.4	Morphological Thinning	76
3.5	Fuzzy Skeleton of Influence Zones	78
3.5.1	Definition Based on Fuzzy Dilations	79
3.5.2	Definitions Based on Distances	80
3.5.3	Illustrative Example (Reproduced from [8])	82
3.6	Conclusion	84
	References	85
TER 4	Unified part-patch segmentation of mesh shapes using surface skeletons	89
	Joost Koehoorn, Cong Feng, Jacek Kustra, Andrei Jalba, and Alexandru Telea	
4.1	Introduction	90
4.2	Related Work	91
4.2.1	Skeletonization	91
4.2.2	Shape Segmentation	93
4.2.3	Summary of Challenges	95
4.3	Method	96
4.3.1	Preliminaries	96
4.3.2	Regularized Surface Skeleton Computation	97
4.3.3	Cut-Space Computation	99
4.3.4	Cut-Space Partitioning	100
4.3.5	Partitioning the Full Surface Skeleton	102
4.3.6	Partition Projection to Surface	104
4.3.7	Part-Based Partition Refinement	105
4.3.8	Unified (Part and Patch) Segmentation	107
4.4	Results	112
4.5	Discussion	115

4.6	Conclusion	119
	References	120
CHAPTER 5	Improving the visual aspect of the skeleton and simplifying its structure	123
	Gabriella Sanniti di Baja and Luca Serino	
5.1	Introduction	123
5.2	Preliminary Notions and Definitions	125
5.3	Tools Improving the Visual Aspect of the Skeleton	127
5.3.1	Zig-zag Straightening	127
5.3.2	Fusion of Close Branch Points	129
5.3.3	Pruning	131
5.4	Experimental Results on the Improvement of Skeleton Visual Aspect	135
5.5	Tools to Simplify Skeleton Structure	138
5.5.1	Polygonal Approximation	140
5.5.2	Building a Linearized Version of the Skeleton	144
5.6	Experimental Results on the Simplification of Skeleton Structure	145
5.7	Conclusion	147
	References	149
CHAPTER 6	Curve skeletonization using minimum-cost path	151
	Dakai Jin, Cheng Chen, Eric A. Hoffman, and Punam K. Saha	
6.1	Introduction	151
6.2	General Principles of Curve Skeletonization	153
6.2.1	Geodesic Distance Transform Based Methods	154
6.2.2	Direct Methods	155
6.2.3	Minimum-Cost Path Based Methods	156
6.3	Curve Skeletonization with Minimum-Cost Path	157
6.3.1	Overall Outline	158
6.3.2	Minimum-Cost Path	161
6.3.3	Centered Minimum-Cost Paths	162
6.3.4	Skeletal Branch Detection	164
6.3.5	Object Volume Marking	165
6.3.6	Skeletal Branch Significance	166
6.3.7	Termination Criterion	166
6.3.8	Algorithm Efficiency	167
6.4	Applications	169
6.4.1	Virtual Colonoscopy and Bronchoscopy	170
6.4.2	Anatomical Labeling of Human Airway Trees	172
6.4.3	Morphologic Assessment of Pulmonary Arteries	173

6.5	Conclusions	174
	References	175
CHAPTER 7	Parallel skeletonization algorithms in the cubic grid based on critical kernels	181
	Gilles Bertrand and Michel Couprie	
7.1	Introduction	181
7.2	Voxel Complexes and Simple Voxels	183
7.3	Critical Cliques	184
7.4	Decreasing Rank Strategy	186
7.5	Asymmetric Thinning	187
7.5.1	Generic Parallel Asymmetric Thinning Scheme	187
7.5.2	Isthmus-Based Asymmetric Thinning	189
7.5.3	Comparison with Other Parallel Curve Skeletonization Methods	191
7.6	Symmetric Thinning	193
7.6.1	Generic Parallel Symmetric Thinning Scheme	194
7.6.2	Isthmus-Based Symmetric Thinning	195
7.7	Characterization of Critical Cliques and k -Isthmuses	197
7.8	Isthmus Persistence and Skeleton Filtering	200
7.9	Hierarchies of Skeletons	202
7.10	Complexity	206
7.11	Conclusion	207
	References	208
CHAPTER 8	Critical kernels, minimal nonsimple sets, and hereditarily simple sets in binary images on n-dimensional polytopal complexes	211
	T.Y. Kong	
8.1	Introduction	212
8.1.1	Background and Prior Work	214
8.1.2	Contributions of This Chapter	217
8.2	Preliminaries: Complexes, Polyhedra, and Binary Images	218
8.2.1	Convex Polytopes	218
8.2.2	Complexes and Pure Complexes	219
8.2.3	Polyhedra	221
8.2.4	Binary Images on Pure Polytopal Complexes	222
8.3	Nonempty Topologically Simple (NETS) Polyhedra	222
8.3.1	Properties of NETS Polyhedra	223
8.3.2	The Axioms That Specify NETS Polyhedra	224
8.3.3	In a Strongly Normal Collection of Nonempty Convex Polytopes, the Union of Any Element with Its Neighbors Is NETS	225

8.3.4	Possible Definitions of NETS Polyhedra Using Homology Groups	226
8.4	Consequences of the NETS Axioms	228
8.4.1	A 0- or 1-Dimensional Complex Is NETS Just If It Is a Tree	229
8.4.2	Collapsible Polyhedra Are NETS, and NETS Polyhedra Never Collapse to Non-NETS Polyhedra	231
8.4.3	A Polyhedron in the Plane or in the Boundary of a 3-Dimensional Convex Polytope Is NETS If and Only If It Is Collapsible	232
8.5	Simple, Hereditarily Simple, and Minimal Nonsimple Sets	233
8.5.1	Simple Is, Attachment Complexes, and Attachment Sets	233
8.5.2	Definitions and Basic Properties of Simple, Hereditarily Simple, and Minimal Nonsimple Sets	235
8.6	Cliques, Cores, and the Critical Kernel	236
8.6.1	$\mathbb{I}$ -Induced Cliques and $\mathbb{I}$ -Essential Cells	237
8.6.2	$\mathbb{I}$ -Cores	238
8.6.3	$\mathbb{I}$ -Regular and $\mathbb{I}$ -Critical Cells; the Critical Kernel of $\mathbb{I}$	239
8.7	Characterizations of P-Simple Is, Hereditarily Simple Sets, and Minimal Nonsimple Sets	240
8.8	A Proof of Theorem 8.5.5 and a Second Proof of the "If" Part of Theorem 8.7.1 Based on NETS-Collapsing	245
8.8.1	NETS-Collapsing and a Proof of Theorem 8.5.5	245
8.8.2	$\mathbb{I}$ -Essential Complexes and Another Proof of the "If" Part of Theorem 8.7.1	251
8.9	Concluding Remarks	253
	References	254

PART 2 APPLICATIONS

CHAPTER 9	Skeletonization in natural images and its application to object recognition	259
	Wei Shen, Kai Zhao, Jiang Yuan, Yan Wang, Zhijiang Zhang, and Xiang Bai	
9.1	Introduction	260
9.2	Related Works	262
9.3	Methodology	264
9.3.1	Network Architecture	264
9.3.2	Skeleton Extraction by Fusing Scale-Associated Side Output	265
9.3.3	Understanding of the Proposed Method	269
9.4	Experimental Results	269

9.4.1	Implementation Details	270
9.4.2	Performance Comparison	271
9.5	Conclusion	283
	Acknowledgments	283
	References	284
CHAPTER 10	Characterization of trabecular bone plate–rod micro-architecture using skeletonization and digital topologic and geometric analysis	287
	Punam K. Saha	
10.1	Introduction	287
10.2	Definitions and Notations	289
10.3	Skeletonization	290
10.4	Digital Topological Analysis	291
10.4.1	Surface–Surface Junction Line Extension	294
10.4.2	Detection of Junction Voxels Between Surfaces and Curves	295
10.5	Volumetric Topological Analysis	297
10.5.1	Geodesic Distance Transform	299
10.5.2	Feature Propagation and Representative	302
10.5.3	Applications	302
10.6	Conclusion	305
	References	305
CHAPTER 11	Medial structure generation for registration of anatomical structures	313
	Sergio Vera, Debora Gil, H.M. Kjer, Jens Fagertun, Rasmus R. Paulsen, and Miguel Á. González Ballester	
11.1	Medial Maps for Reliable Extraction of Anatomical Medial Surfaces	314
11.2	Extracting Anatomical Medial Surfaces Using Medialness Maps	316
11.2.1	Gaussian Steerable Medial Maps	317
11.3	Validation Framework for Medial Anatomy Assessment	322
11.3.1	Synthetic Database	322
11.3.2	Medial Surface Quality Metrics	323
11.4	Validation Experiments	324
11.4.1	Medial Surface Quality	325
11.4.2	Reconstruction Power for Clinical Applications	327
11.5	Application to Cochlea Registration	327
11.5.1	Material and Methods	330
11.5.2	Skeletonization	330
11.5.3	Image Registration	331

11.5.4	Evaluation	333
11.5.5	Results	335
11.6	Discussion	337
	Acknowledgments	340
	References	340
CHAPTER 12	Skeleton-based fast, fully automated generation of vessel tree structure for clinical evaluation of blood vessel systems	345
	Kristína Lidayová, Hans Frimmel, Chunliang Wang, Ewert Bengtsson, and Örjan Smedby	
12.1	Introduction	346
12.2	Medical Context	347
12.2.1	Clinical Evaluation of the Peripheral Arterial System	347
12.2.2	Need for Image Postprocessing	349
12.3	Background	350
12.3.1	Previous Methods	350
12.3.2	From Colon to Blood Vessels	352
12.4	Fast Skeleton-Based Generation of the Centerline Tree	354
12.4.1	Parameter Selection	355
12.4.2	The Artery Nodes Detection	359
12.4.3	The Artery Nodes Connection	364
12.4.4	Anatomy-Based Analysis	365
12.4.5	Vascular Segmentation Based on the Vascular Centerline Tree	366
12.5	Validation of the Vascular Centerline Tree	367
12.5.1	Computed Angiographic Images of the Lower Limbs	368
12.5.2	Evaluation of Automatically Selected Changeable Parameters	368
12.5.3	Reference and United Skeleton	369
12.5.4	Skeleton Evaluation	371
12.5.5	Computation Time	374
12.6	Adapting the Algorithm to Other Applications	375
12.7	Discussion and Conclusion	376
12.8	Future Development of the Method	379
	Acknowledgments	379
	References	379
	Index	383