

University of Groningen

## Generalized Connected Morphological Operators for Robust Shape Extraction

Ouzounis, Georgios Konstantinou

**IMPORTANT NOTE:** You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

*Document Version*

Publisher's PDF, also known as Version of record

*Publication date:*

2009

[Link to publication in University of Groningen/UMCG research database](#)

*Citation for published version (APA):*

Ouzounis, G. K. (2009). Generalized Connected Morphological Operators for Robust Shape Extraction s.n.

**Copyright**

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

**Take-down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

**Generalized Connected Morphological Operators  
for  
Robust Shape Extraction**

**Georgios K. Ouzounis**



Netherlands Organisation for Scientific Research

This research project was funded by the Netherlands Organization for Scientific Research under project number 612.065.202.

ISBN: 978-90-367-3698-5

**RIJKSUNIVERSITEIT GRONINGEN**

**Generalized Connected Morphological Operators  
for  
Robust Shape Extraction**

Proefschrift

ter verkrijging van het doctoraat in de  
Wiskunde en Natuurwetenschappen  
aan de Rijksuniversiteit Groningen  
op gezag van de  
Rector Magnificus, dr. F. Zwarts,  
in het openbaar te verdedigen op  
vrijdag 16 januari 2009  
om 14:45 uur

door

**Georgios Konstantinou Ouzounis**

geboren op 13 januari 1977  
te Esslingen am Neckar, Duitsland

Promotor : Prof. dr. N. Petkov  
Copromotor : Dr. M.H.F. Wilkinson  
Beoordelingscommissie : Prof. dr. S. Acton  
Prof. dr. P. Maragos  
Prof. dr. W. Niessen

ISBN: 978-90-367-3698-5

---

*To the memory of a great man,*  
Georgios Christou Ouzounis



---

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Summary of the Work and Contributions . . . . .	2
1.1.1	Mask-Based Second-Generation Connectivity . . . . .	3
1.1.2	Partition-Induced Connectivity . . . . .	6
1.1.3	Hyperconnectivity . . . . .	7
1.2	Thesis Organization . . . . .	8
<b>2</b>	<b>Mask-Based Second-Generation Connectivity and Attribute Filters</b>	<b>11</b>
2.1	Introduction . . . . .	11
2.2	Theoretical Background . . . . .	14
2.2.1	Connectivity Classes and Connectivity Openings . . . . .	14
2.2.2	Second-Generation Connectivity . . . . .	15
2.2.3	Attribute Openings . . . . .	18
2.3	Drawbacks of Conventional Second-Generation Connectivity . . . . .	19
2.4	Mask-Based Second-Generation Connectivity . . . . .	21
2.4.1	Mask-Based Connectivity . . . . .	21
2.4.2	Gray-Scale Mask-Based Attribute Filters . . . . .	25
2.5	Computing Second-Generation Attribute Filters . . . . .	26
2.5.1	The Max-Tree Algorithm . . . . .	26
2.5.2	The Dual-Input Max-Tree Algorithm . . . . .	27
2.5.3	Filtering and Image Restitution . . . . .	32
2.6	Experiments and Discussion . . . . .	33
2.6.1	3-D Biomedical Datasets . . . . .	36
2.6.2	Images of Proteins . . . . .	36
2.6.3	Computational Complexity . . . . .	38
2.7	Conclusions and Further Work . . . . .	38



---

<b>3</b>	<b>Filament Enhancement by Non-Linear Volumetric Filtering using Clustering-Based Connectivity</b>	<b>41</b>
3.1	Introduction . . . . .	41
3.2	Theory . . . . .	42
3.2.1	Connectivity Classes and Openings . . . . .	42
3.2.2	Clustering-Based Connectivity . . . . .	44
3.3	Shape Filters . . . . .	45
3.4	Experiments . . . . .	46
3.5	Discussion . . . . .	50
<b>4</b>	<b>A Parallel Implementation of the Dual-Input Max-Tree Algorithm for Attribute Filtering</b>	<b>53</b>
4.1	Introduction . . . . .	53
4.2	Attribute filters . . . . .	54
4.3	The Max-Tree algorithm . . . . .	55
4.4	Including union-find in the Max-Tree . . . . .	56
4.5	The dual-input mode . . . . .	57
4.6	Concurrent merging of Max-Trees . . . . .	59
4.7	Performance testing and complexity . . . . .	62
4.8	Conclusions . . . . .	63
<b>5</b>	<b>Partition-Induced Connections and Operators for Pattern Analysis</b>	<b>65</b>
5.1	Introduction . . . . .	65
5.2	Theory . . . . .	67
5.2.1	Connections and Connected Operators . . . . .	67
5.2.2	Second-Generation Connectivity . . . . .	68
5.2.3	Attribute Filters . . . . .	69
5.2.4	Granulometries and Pattern Spectra . . . . .	70
5.3	Partition-Induced Connections . . . . .	71
5.3.1	Partitions and Connections . . . . .	71
5.3.2	Countering Oversegmentation with $\pi$ -Connections . . . . .	72
5.3.3	$\pi$ -connected Attribute Filters . . . . .	73
5.3.4	Gray-scale Limitations . . . . .	75
5.4	Gray-scale Pattern Analysis . . . . .	76
5.4.1	Gray-Scale Pattern Spectra Using Max-Trees . . . . .	76
5.4.2	Binned 2D Shape-Size Spectra . . . . .	77
5.5	Diatom Identification Experiments . . . . .	79
5.5.1	The ADIAC Diatom Image Database . . . . .	79
5.5.2	Experimental Methods and Parametrization . . . . .	79

## Contents

---

5.5.3	The C4.5 Decision Tree Classifier . . . . .	80
5.5.4	Experiments . . . . .	80
5.5.5	Performance Optimization Using Combined Methods . . . . .	81
5.6	Discussion of Results . . . . .	83
5.7	Conclusions . . . . .	85
<b>6</b>	<b>Hyperconnected Attribute Filters Based on <math>k</math>-Flat Zones for 3D Medical Imaging</b>	<b>87</b>
6.1	Introduction . . . . .	87
6.2	Connections, Partitions and Operators . . . . .	90
6.2.1	Connections and Partitions . . . . .	90
6.2.2	Attribute Filters . . . . .	91
6.2.3	Extensions to Gray-Scale . . . . .	92
6.3	Hyperconnections . . . . .	93
6.3.1	Hyperconnectivity Classes and Covers . . . . .	93
6.3.2	Covers of $k$ -Flat Zones . . . . .	96
6.3.3	Attribute Filters Based on $k$ -Flat Zones . . . . .	98
6.4	The $k$ -Subtractive Filtering Rule for the Max-Tree Algorithm . . . . .	100
6.4.1	The Max-Tree Algorithm . . . . .	100
6.4.2	The $k$ -subtractive Implementation . . . . .	101
6.5	Applications on Volumetric Data and Discussion . . . . .	103
6.5.1	The foot data set . . . . .	104
6.5.2	The CT-Knee data set . . . . .	104
6.5.3	The MRI-Head data set . . . . .	105
6.5.4	The CT-Chest data set . . . . .	105
6.5.5	The spine data set . . . . .	108
6.5.6	Parameter Selection and Computational Complexity . . . . .	108
6.6	Conclusions . . . . .	109
<b>7</b>	<b>Summary</b>	<b>111</b>
7.1	Conclusions . . . . .	111
7.2	Future Work . . . . .	113
	<b>Samenvatting</b>	<b>115</b>
	<b>Publications</b>	<b>119</b>
	<b>Acknowledgments</b>	<b>121</b>
	<b>Bibliography</b>	<b>123</b>

