

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).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

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.

Bibliography

- [1] B. Appleton and H. Talbot. Efficient path openings and closings. In *Mathematical Morphology: 40 Years On; Proc. 7th Int. Symp. Math. Morphology*, pages 33–42, Paris, 18-20 April 2005.
- [2] J. A. Bangham, R. Harvey, P. D. Ling, and R. V. Aldridge. Morphological scale-space preserving transforms in many dimensions. *J. Electr. Imag.*, 5:283–299, 1996.
- [3] J. A. Bangham, R. Harvey, P. D. Ling, and R. V. Aldridge. Nonlinear scale-space from n-dimensional sieves. In *Proceedings IEEE ECCV'96*, volume 1064 of *Lecture Notes in Computer Science*, pages 189–198, 1996.
- [4] N. Bouaynaya, M. Charif-Chefchaoui, and D. Schonfeld. Theoretical foundations of spatially-variant mathematical morphology part I: Binary images. *IEEE Trans. Pattern Anal. Mach. Intell.*, 30(5):823–836, 2008.
- [5] N. Bouaynaya and D. Schonfeld. Theoretical foundations of spatially-variant mathematical morphology part II: Gray-level images. *IEEE Trans. Pattern Anal. Mach. Intell.*, 30(5):837–850, 2008.
- [6] U.M. Braga-Neto and J. Goutsias. Multiresolution connectivity: An axiomatic approach. In *Mathematical Morphology and its Applications to Image and Signal Processing*, pages 159–168, 2000.
- [7] U.M. Braga-Neto and J. Goutsias. Connectivity on complete lattices: New results. *Comp. Vis. Image Understand.*, 85:22–53, 2002.
- [8] U.M. Braga-Neto and J. Goutsias. A multiscale approach to connectivity. *Comp. Vis. Image Understand.*, 89:70–107, 2003.
- [9] U.M. Braga-Neto and J. Goutsias. A theoretical tour of connectivity in image processing and analysis. *J. Math. Imag. Vis.*, 19:5–31, 2003.
- [10] U.M. Braga-Neto and J. Goutsias. Grayscale level connectivity: Theory and applications. *IEEE Trans. Image Proc.*, 13(12):1567–1580, 2004.
- [11] E. J. Breen and R. Jones. Attribute openings, thinnings and granulometries. *Comp. Vis. Image Understand.*, 64(3):377–389, 1996.

- [12] J. M. H. Du Buf and M. M. Bayer, editors. *Automatic Diatom Identification*. Series in Machine Perception and Artificial Intelligence. World Scientific Publishing Co., Singapore, 2002.
- [13] V. Caselles and P. Monasse. Grain filters. *J. Math. Imag. Vis.*, 17:249–270, 2002.
- [14] F. Cheng and A. N. Venetsanopoulos. An adaptive morphological filter for image processing. *IEEE Trans. Image Proc.*, 1:533–539, 1992.
- [15] A.C.S. Chung. Image segmentation methods for detecting blood vessels in angiography. In *Int. Conf. Automation, Robotics and Computer Vision*, pages 1–6, 2006.
- [16] J. Crespo, R. W. Schafer, J. Serra, C. Gratin, and F. Meyer. The flat zone approach: a general low-level region merging segmentation method. *Signal Processing*, 62:37–60, 1997.
- [17] R. Diestel. *Graph Theory*. New York: Springer-Verlag, 1997.
- [18] Y. P. Du and D. L. Parker. Vessel enhancement filtering in three-dimensional MR angiograms using long-range signal correlation. *J. Magn. Reson. Imag.*, 7:447–450, 1997.
- [19] A. N. Evans. Vector area morphology for motion field smoothing and interpretation. *IEE Proc.-Vis. Image Signal Process.*, 150:219–226, 2003.
- [20] N. Flasque and M. Desvignes. Accurate detection of 3d tubular tree structures. In *Proc. Int. Conf. Image Processing*, pages Vol III: 436–439, 2000.
- [21] A. F. Frangi, W. J. Niessen, and M. A. Viergever K. L. Vincken. Multiscale vessel enhancement filtering. In W. M. Wells, A. Colchester, and S.L Delp, editors, *In Medical Image Computing and Computer-Assisted Intervention, MICCAI 1998, Proceedings*, volume 1496 of *Lecture Notes in Computer Science*, pages 130–137. Springer Verlag, Berlin, Germany, 1998.
- [22] A.F. Frangi, A.A. Amini, and E. Bullitt. Vascular imaging. *IEEE Trans. Medical Imaging*, 24(4):433–435, April 2005.
- [23] D. Gatica-Perez, C. Gu, M. T. Sun, and S. Ruiz-Correa. Extensive partition operators, gray-level connected operators, and region merging/classification segmentation algorithms: Theoretical links. *IEEE Trans. Image Proc.*, 10:1332–1345, 2001.
- [24] D. Gimenez and A. N. Evans. An evaluation of area morphology scale-spaces for colour images. *Comp. Vis. Image Understand.*, 110(1):32–42, 2008.
- [25] S. E. Grigorescu, N. Petkov, and P. Kruizinga. Comparison of texture features based on gabor filters. *IEEE Trans. Image Proc.*, 11(10):1160–1167, 2002.
- [26] H. J. A. M. Heijmans. *Morphological Image Operators*. Academic Press, Boston, 1994.
- [27] H. J. A. M. Heijmans. Morphological filters. In *Proc. Summer School Morph. Image Signal Proc.*, Zakopane, Poland, 1995.
- [28] H. J. A. M. Heijmans. Composing morphological filters. *IEEE Trans. Image Proc.*, 6(5):713–723, 1997.
- [29] H. J. A. M. Heijmans. Connected morphological operators for binary images. *Comp. Vis. Image Understand.*, 73:99–120, 1999.

- [30] A. C. Jalba, J. B. T. M. Roerdink, and M. H. F. Wilkinson. Morphological hat-transform scale spaces and their use in texture classification. In *Proc. Int. Conf. Image Proc. 2003*, volume I, pages 329–332, Barcelona, Spain, September 14-17 2003.
- [31] A. C. Jalba, J. B. T. M. Roerdink, and M. H. F. Wilkinson. Morphological hat-transform scale spaces and their use in pattern classification. *Pattern Recognition*, 37(5):901–915, 2004.
- [32] A. C. Jalba, M. H. F. Wilkinson, and J. B. T. M. Roerdink. Automatic diatom identification using contour analysis by morphological curvature scale spaces. *Machine Vision and Applications*, 16(4):217–228, 2005.
- [33] A. C. Jalba, M. H. F. Wilkinson, and J. B. T. M. Roerdink. Shape representation and recognition through morphological curvature scale spaces. *IEEE Trans. Image Processing*, 15(2):331–341, 2006.
- [34] A. C. Jalba, M. H. F. Wilkinson, J. B. T. M. Roerdink, M. M. Bayer, and S. Juggins. Automatic diatom identification using contour analysis by morphological curvature scale spaces. IWI-report 2001-9-05, Institute for Mathematics and Computing Science, University of Groningen, Groningen, The Netherlands, 2001.
- [35] R. Jones. Connected filtering and segmentation using component trees. *Comp. Vis. Image Understand.*, 75:215–228, 1999.
- [36] J. C. Klein. *Conception et réalisation d'une unité logique pour l'analyse quantitative d'images*. PhD thesis, Nancy University, France, 1976.
- [37] T. Y. Kong and A. Rosenfeld. Digital topology: Introduction and survey. *Comp. Vision Graph. Image Proc.*, 48:357–393, 1989.
- [38] K. Krissian. Flux-based anisotropic diffusion applied to enhancement of 3-d angiogram. *IEEE Trans. Medical Imaging*, 21(11):1440–1442, November 2002.
- [39] R. Lerallut, E. Decencière, and F. Meyer. Image filtering using morphological amoebas. In *Mathematical Morphology: 40 Years On; Proc. 7th Int. Symp. Math. Morphology*, pages 13–22, Paris, 18-20 April 2005.
- [40] R. Lerallut, E. Decencière, and F. Meyer. Image filtering using morphological amoebas. *Image Vis. Comput.*, 25(4):395–404, 2007.
- [41] P. Maragos. Pattern spectrum and multiscale shape representation. *IEEE Trans. Pattern Anal. Mach. Intell.*, 11:701–715, 1989.
- [42] P. Maragos and G. Evangelopoulos. Leveling cartoons, texture energy markers, and image decomposition. In *Proc. Int. Symp. Math. Morphology (ISMM) 2007*, pages 125–138, 2007.
- [43] P. Maragos and R. D. Ziff. Threshold superposition in morphological image analysis systems. *IEEE Trans. Pattern Anal. Mach. Intell.*, 12(5):498–504, 1990.
- [44] G. Matheron. *Random Sets and Integral Geometry*. John Wiley, 1975.
- [45] G. Matheron and J. Serra. Strong filters and connectivity. In J. Serra (Ed.), editor, *Image Analysis and Mathematical Morphology*, volume 2, pages 141–157. Academic Press: London, 1988.

- [46] A. Meijster, M. A. Westenberg, and M. H. F. Wilkinson. Interactive shape preserving filtering and visualization of volumetric data. In *Fourth IASTED Conf Comp. Signal Image Proc., SIP2002*, pages 640–643, Kauai, Hawaii, USA, August 12-14 2002.
- [47] A. Meijster and M. H. F. Wilkinson. A comparison of algorithms for connected set openings and closings. *IEEE Trans. Pattern Anal. Mach. Intell.*, 24(4):484–494, 2002.
- [48] F. Meyer. Levelings, image simplification filters for segmentation. *J. Math. Imag. Vis.*, 20(1–2):59–72, 2004.
- [49] P. Monasse and F. Guichard. Fast computation of a contrast invariant image representation. *IEEE Trans. Image Proc.*, 9:860–872, 2000.
- [50] P. Monasse and F. Guichard. Scale-space from a level lines tree. *J. Vis. Commun. Image Repres.*, 11:224–236, 2000.
- [51] B. Naegel, N. Passat, N. Boch, and M. Kocher. Segmentation using vector-attribute filters: Methodology and application to dermatological imaging. In *Proc. Int. Symp. Math. Morphology (ISMM) 2007*, pages 239–250, 2007.
- [52] L. Najman and M. Couprie. Building the component tree in quasi-linear time. *IEEE Trans. Image Proc.*, 15:3531–3539, 2006.
- [53] M. Orkisz, M. Hernandez-Hoyos, P. Douek, and I. Magnin. Advances of blood vessel morphology analysis in 3D magnetic resonance images. *Mach. Vis. Graph.*, 9:463–471, 2000.
- [54] G. K. Ouzounis and M. H. F. Wilkinson. Countering oversegmentation in partitioning-based connectivities. In *Proc. Int. Conf. Image Processing.*, pages 844–847, 2005.
- [55] G. K. Ouzounis and M. H. F. Wilkinson. Second-order connected attribute filters using max-trees. In C. Ronse, L. Najman, and E. Decenciere, editors, *Mathematical Morphology: 40 Years On; Proc. 7th Int. Symp. Math. Morphology*, volume 30 of *Computational Imaging and Vision*, pages 65–74, Dordrecht, 2005. Springer-Verlag.
- [56] G. K. Ouzounis and M. H. F. Wilkinson. Filament enhancement by non-linear volumetric filtering using clustering-based connectivity. In Nanning Zheng, Xiaoyi Jiang, and Xuguang Lan, editors, *Advances in Machine Vision, Image Processing, and Pattern Analysis, International Workshop on Intelligent Computing in Pattern Analysis/Synthesis, IWICPAS*, volume 4153 of *Lecture Notes in Computer Science*, pages 317–327. Springer, 2006.
- [57] G. K. Ouzounis and M. H. F. Wilkinson. Mask-based second-generation connectivity and attribute filters. *IEEE Trans. Pattern Anal. Mach. Intell.*, 29(6):990–1004, 2007.
- [58] G. K. Ouzounis and M. H. F. Wilkinson. Hyperconnected attribute filters based on k-flat zones for 3d medical imaging. *IEEE Trans. Pattern Anal. Mach. Intell.*, Submitted.
- [59] G. K. Ouzounis and M. H. F. Wilkinson. Partition-induced connections and operators for pattern analysis. *Pattern Recognition*, Submitted.
- [60] N. Ray and S.T. Acton. Inclusion filters: a class of self-dual connected operators. *IEEE Trans. Image Proc.*, 14(11):1736–1746, 2005.
- [61] C. Ronse. Openings: Main properties, and how to construct them. Unpublished manuscript, Philips Research Laboratory Brussels, 1990.

- [62] C. Ronse. Set-theoretical algebraic approaches to connectivity in continuous or digital spaces. *Journal of Mathematical Imaging and Vision*, 8:41–58, 1998.
- [63] P. Salembier. Binary partition tree as an efficient representation for image processing, segmentation and information retrieval. *IEEE Trans. Image Proc.*, 9(4):561–576, 2000.
- [64] P. Salembier, P. Brigger, J. R. Casas, and M. Pardàs. Morphological operators for image and video compression. *IEEE Trans. Image Proc.*, 5:881–898, 1996.
- [65] P. Salembier, A. Oliveras, and L. Garrido. Anti-extensive connected operators for image and sequence processing. *IEEE Trans. Image Proc.*, 7:555–570, 1998.
- [66] P. Salembier and J. Serra. Flat zones filtering, connected operators, and filters by reconstruction. *IEEE Trans. Image Proc.*, 4:1153–1160, 1995.
- [67] J. Serra. *Image Analysis and Mathematical Morphology*, volume 1. Academic Press, New York, 1982.
- [68] J. Serra, editor. *Image Analysis and Mathematical Morphology. II: Theoretical Advances*. Academic Press, London, 1988.
- [69] J. Serra. Connectivity on complete lattices. *Journal of Mathematical Imaging and Vision*, 9:231–251, 1998.
- [70] J. Serra. Connections for sets and functions. In *Fundamenta Informaticae*, volume 41, pages 147–186, 2000.
- [71] J. Serra. Viscous lattices. In *Mathematical Morphology; Proc. 6th Int. Symp. Math. Morphology*, pages 79–90, 2002.
- [72] J. Serra. A lattice approach to image segmentation. *Journal of Mathematical Imaging and Vision*, 24:83–130, 2006.
- [73] J. Serra and P. Salembier. Connected operators and pyramids. In *Proc. of SPIE Image Algebra and Mathematical Morphology*, volume 2030, pages 65–76, San Diego, California, USA., 1993.
- [74] A. Sofou, C. Tzafestas, and P. Maragos. Segmentation of soilsection images using connected operators. In *Proc. Int. Conf. Image Proc. 2001 (ICIP-2001)*, pages 1087–1090, Thessaloniki, Greece, October 2001.
- [75] P. Soille. Beyond self-duality in morphological image analysis. *Image and Vision Computing*, 23:249–257, 2005.
- [76] P. Soille. Constrained connectivity for hierarchical image decomposition and simplification. *IEEE Trans. Pattern Anal. Mach. Intell.*, 30(7):1132–1145, 2008.
- [77] P. Soille, E. Breen, and R. Jones. Recursive implementation of erosions and dilations along discrete lines at arbitrary angles. *IEEE Trans. Pattern Anal. Mach. Intell.*, 18(5):562–567, 1996.
- [78] H. Talbot and B. Appleton. Efficient complete and incomplete path openings and closings. *Image Vis. Comput.*, 25(4):416–425, 2007.
- [79] R. E. Tarjan. Efficiency of a good but not linear set union algorithm. *J. ACM*, 22:215–225, 1975.
- [80] I. R. Terol-Villalobos and D. Vargas-Vázquez. Openings and closings with reconstruction criteria: a study of a class of lower and upper levelings. *J. Electron. Imaging*, 14(1):013006, 2005.

- [81] F. Tushabe and M. H. F. Wilkinson. Image preprocessing for compression: Attribute filtering. In *Proc. World Congress on Engineering & Computer Science 2007*, pages 999–1005, 2007.
- [82] F. Tushabe and M. H. F. Wilkinson. Content-based image retrieval using combined 2d attribute pattern spectra. In *Proc. Clef'2007*, 2008. In press.
- [83] C. Tzafestas and P. Maragos. Shape connectivity: Multiscale analysis and application to generalized granulometries. *Journal Math. Imaging and Vision*, 17:109–129, 2002.
- [84] E. R. Urbach, N. J. Boersma, and M. H. F. Wilkinson. Vector-attribute filters. In C. Ronse, L. Najman, and E. Decenciere, editors, *Mathematical Morphology: 40 Years On; Proc. 7th Int. Symp. Math. Morphology*, pages 95–104. Springer-Verlag, Dordrecht, 2005.
- [85] E. R. Urbach, J. B. T. M. Roerdink, and M. H. F. Wilkinson. Connected shape-size pattern spectra for rotation and scale-invariant classification of gray-scale images. *IEEE Trans. Pattern Anal. Mach. Intell.*, 29(2):272–285, 2007.
- [86] E. R. Urbach and M. H. F. Wilkinson. Shape-only granulometries and grey-scale shape filters. In H. Talbot and R. Beare, editors, *Mathematical Morphology; Proc. 6th Int. Symp. Math. Morphology*, pages 305–314, Collingwood, Australia, 2002. CSIRO Publishing.
- [87] L. Vincent. Morphological area openings and closings for greyscale images. In *Proc. NATO Shape in Picture Workshop*, pages 197–208, Driebergen, The Netherlands, September 1992.
- [88] L. Vincent. Morphological grayscale reconstruction in image analysis: application and efficient algorithm. *IEEE Trans. Image Proc.*, 2:176–201, 1993.
- [89] L. Vincent. Granulometries and opening trees. *Fundamenta Informaticae*, 41:57–90, 2000.
- [90] M. A. Westenberg, J. B. T. M. Roerdink, and M. H. F. Wilkinson. Volumetric attribute filtering and interactive visualization using the max-tree representation. *IEEE Trans. Image Proc.*, 16(12):2943–2952, 2007.
- [91] M. H. F. Wilkinson. Attribute-space connected filters. In C. Ronse, L. Najman, and E. Decencie, editors, *Mathematical Morphology: 40 Years On; Proc. 7th Int. Symp. Math. Morphology*, pages 85–94. Springer-Verlag, Dordrecht, 2005.
- [92] M. H. F. Wilkinson. Attribute-space connectivity and connected filters. *Image Vis. Comput.*, 25:426–435, 2007.
- [93] M. H. F. Wilkinson, H. Gao, W. H. Hesselink, J. E. Jonker, and A. Meijster. Concurrent computation of attribute filters using shared memory parallel machines. *IEEE Trans. Pattern Anal. Mach. Intell.*, 30(10):1800–1813, 2008.
- [94] M. H. F. Wilkinson and M. A. Westenberg. Shape preserving filament enhancement filtering. In W. J. Niessen and M. A. Viergever, editors, *Proc. MICCAI'2001*, volume 2208 of *Lecture Notes in Computer Science*, pages 770–777, 2001.
- [95] O. Wink, W. J. Niessen, and M. A. Viergever. Fast delineation and visualization of vessels in 3-D angiographic images. *IEEE Transactions on Medical Imaging*, 19:337–346, 2000.
- [96] W.C.K. Wong, A.C.S. Chung, and S.C.H. Yu. Local orientation smoothness prior for vascular segmentation of angiography. In *European Conf. Computer Vision*, pages Vol II: 353–365, 2004.