university of groningen

University Medical Center Groningen

University of Groningen

Efficient morphological tools for astronomical image processing

Moschini, Ugo

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:
2016

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Moschini, U. (2016). *Efficient morphological tools for astronomical image processing*. [Groningen]: University of Groningen.

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.

Download date: 22-06-2020

Efficient Morphological Tools for Astronomical Image Processing

Ugo Moschini

The research work described in this thesis was carried out at the Intelligent Systems group of the Johann Bernoulli Institute for Mathematics and Computer Science, University of Groningen, The Netherlands. This work was financially supported by the Netherlands Organisation for Scientific Research (NWO) under project number 612.001.110.

Cover background: VISTA gigapixel mosaic of the central parts of the Milky Way. Id: eso1242. Credit: ESO/VVV Survey/D. Minniti. Acknowledgement: Ignacio Toledo, Martin Kornmesser.
Front cover detail: photo of a tea plantation taken by the author in Darjeeling, India. The whole plantation is made of small tea shrubs: likewise, the parallel construction of a max-tree occurs by merging together the small sub-trees computed by the threads.

Printed by Ipskamp Drukkers BV, Enschede, The Netherlands.

ISBN: 978-90-367-8848-9 (printed version)
ISBN: 978-90-367-8846-5 (digital version)

university of groningen

Efficient Morphological Tools for Astronomical Image Processing

PhD thesis

to obtain the degree of PhD at the
University of Groningen
on the authority of the
Rector Magnificus Prof. E. Sterken
and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on

Friday 13 May 2016 at 12.45 hours

by

Ugo Moschini

born on 14 February 1983
in Pisa, Italy

Supervisors
Prof. N. Petkov
Prof. S.C. Trager

Co-supervisor
Dr. M.H.F. Wilkinson

Assessment Committee
Prof. S.T. Acton
Prof. J.B.T.M. Roerdink
Prof. P. Salembier

to my grandma Nonna Vera,
and her beloved Firenze.

Contents

List of Figures **v**

List of Tables **vi**

List of Algorithms **vii**

Acknowledgements **ix**

1 Introduction **1**
1.1 Scope 2
1.2 Thesis organization 5

2 Mask Connectivity by Viscous Closings: Linking Merging Galaxies without Merging Double Stars **7**
2.1 Introduction 8
2.2 Second-generation connectivity 9
2.3 Standard and Viscous operators 11
2.4 Experiments and Discussion 13
2.4.1 Evaluation of the experiments 14
2.4.2 A visual evaluation 17
2.5 Conclusions 18

3 Improved Detection of Faint Extended Astronomical Objects through Statistical Attribute Filtering **21**
3.1 Introduction 22
3.2 Background estimation 23
3.2.1 Is a constant a good fit? 26
3.2.2 Comparison of the background estimate w.r.t. SExtractor . . . 28
3.3 Connected filtering on a max-tree structure 29
3.4 Identifying significant nodes 30
3.4.1 Significance test 1: `power` given `area` of the node. 31
3.4.2 Simulating distributions 32

3.4.3 Significance test 2: `powerAlt` given `area` and `distance`. . . 32
3.4.4 Significance test 3: `powerAlt` given `area`. 33
3.4.5 Significance test 4: `powerAlt` given `area` with smoothing . . 34
3.4.6 Testing the nodes 34
3.4.7 Discussion on the significance level α 35
3.5 Finding objects 35
3.5.1 Moving object markers up: parameter λ 35
3.6 MTObjects vs Source Extractor 37
3.6.1 Object detection 38
3.6.2 Object fragmentation 40
3.6.3 Dust lanes and artifacts 41
3.7 Speed performance 42
3.8 Conclusions and future work 43

4 A Hybrid Shared-Memory Parallel Max-Tree Algorithm for Extreme Dynamic-Range Images 45
4.1 Introduction 46
4.2 The max-tree structure 47
4.3 State of the art sequential algorithms for XDR images 48
4.4 Two important max-tree algorithms 49
4.4.1 The Tarjan's union-find algorithm 49
4.4.2 The sequential Berger algorithm. 50
4.4.3 The parallel hierarchical queue algorithm 53
4.5 Issues with possible parallel algorithms for XDR images 55
4.6 The parallel hybrid algorithm 56
4.7 The *pilot* max-tree 58
4.8 The refinement stage 60
4.8.1 Intensity $\overline{f}(q) \in \boldsymbol{H_i}$ 62
4.8.2 Intensity $\overline{f}(q) \notin \boldsymbol{H_i}$ 62
4.9 Thread-safety and correctness 63
4.10 Time complexity and memory use 64
4.11 Performance testing 65
4.11.1 Performance tests on simulated images 67
4.11.2 Considerations on completion time and speed-up 69
4.11.3 Performance tests on real-world images 71
4.12 Conclusions 73

5 Towards Better Segmentation of Large Floating Point 3D Astronomical Data Sets: First Results 75
5.1 Introduction 76
5.2 Building max-trees of floating point data sets in parallel 78

5.3 Attribute filter for astronomical object segmentation 78
5.4 Segmentation of 3D radio cubes 79
5.5 Performance testing 82
5.6 Conclusions 82

6 Concurrent Computation of Connected Pattern Spectra for Very Large Image Information Mining 85
6.1 Introduction 86
6.2 Connected filters 88
6.2.1 The max-tree structure 88
6.2.2 Connected Pattern Spectra 88
6.3 The parallel algorithm 89
6.4 Results 91
6.5 Discussion and Conclusions 92

7 Parallel 2D local pattern spectra of invariant moments for galaxy classification 95
7.1 Introduction 96
7.2 Max-tree object segmentation 97
7.3 Moments 98
7.4 Parallel local pattern spectra 99
7.5 Classifying galaxies: the experiment 100
7.6 Classification results and speed performance 101
7.7 Conclusions and future work 106

8 Viscous-Hyperconnected Attribute Filters: A First Algorithm 109
8.1 Introduction 110
8.2 Viscous-Hyperconnectivity class 111
8.3 Viscous-Hyperconnected filtering 113
8.3.1 The algorithm 114
8.4 Implementation notes 117
8.4.1 Eroding the input image 117
8.4.2 Computing the nodes within B_p and the common ancestor . . 117
8.5 Filtering results and performance 118
8.6 Edge preservation issues 120
8.7 Conclusions 120

9 Summary and Outlook 123
9.1 Summary 123
9.2 Outlook 126

Samenvatting 129

Bibliography **133**

Research Activities **143**

Curriculum Vitae **145**

List of Figures

1.1 Example of connected filtering 3

2.1 A pair of interacting galaxies 9
2.2 Standard connectivity and mask connectivity 10
2.3 Effects of different mask images 11
2.4 Structuring element radius as a function of grey level 12
2.5 Measuring level of connectivity in two closely-spaced sources 14
2.6 The reconstructed level of the adjacent component 16
2.7 Reconstructed star with several mask images 17
2.8 Reconstructed galaxy with several mask images 18

3.1 Segmentations of merging galaxies 24
3.2 Rejection rate for squared flat tiles 26
3.3 Distribution of the β quantity 27
3.4 Image with β outliers 27
3.5 Other examples with β outliers 27
3.6 Average background estimate 28
3.7 Sextractor background estimate compared to the constant estimate . 28
3.8 Object shape distortion when background is not constant 29
3.9 Peak components and max-tree 29
3.10 Rejection boundaries 33
3.11 Stars simulated by IRAF software 37
3.12 MTObjects identifies better fainter outer regions and the nested objects 39
3.13 Comparison of objects with faint extended regions 39
3.14 Sparse and dense stars' grids 40
3.15 Fragmented simulated object 41
3.16 Fragmentation of a thin faint filament between two galaxies 41
3.17 Dust lanes 42
3.18 Artefacts 42

4.1 Field of view containing stars and two large interacting galaxies . . . 46
4.2 Quantized image and its max-tree 47
4.3 Performance of existing parallel algorithms 54
4.4 Spatial and intensity partitions 56
4.5 Pixels are sorted according to their intensity 56

4.6 Descent through the hierarchy in the quantized tree 60
4.7 Merging union-find sets 63
4.8 Example images: ESO, PRAGUE, LOFAR 67
4.9 Performance on simulated images 68
4.10 Speed-up of each phase of the parallel algorithm 68
4.11 Completion time of each phase of the parallel algorithm 70
4.12 Performance with several *level root fixing* techniques 71
4.13 Performance and speed-up on real-world images 72

5.1 Segmentations of two merging galaxies 76
5.2 Radio cube segmentations 77
5.3 Radio cube segmentation by channel 80
5.4 Moment-0 image of the identified sources in the WSRT cube 81

6.1 Pattern spectrum of a remote sensing image 87
6.2 Performance and speed-up 92

7.1 Filament of a galaxy better segmented by our method 97
7.2 Examples of correct and wrong classification of galaxies 104
7.3 Difficult cases for the classifier 105

8.1 The leakage problem 111
8.2 Viscous hyper-connected components can overlap 112
8.3 Building and updating the max-tree of the cores 116
8.4 Attribute updating 117
8.5 Test images and performance 119
8.6 The edge-preserving issue 120

List of Tables

2.1 Parameters of the mask images 15

4.1 Simulated and real-world test images 66
4.2 Summary of the performance of the algorithms 66

7.1 Parameters of the pattern spectra 100
7.2 Classification with normalized ps of all the components 102
7.3 Classification with normalized ps of components larger than 4 px . . 102

7.4 Classification with not normalized ps of all the components 103
7.5 Classification with not normalized ps of components larger than 4 px 103
7.6 Execution time and speed-up values 106

List of Algorithms

3.1 IsFlat: find flat tiles 25
3.2 SignificantNodes: mark the nodes as significant 34
3.3 FindObjects: assign nodes to objects 35
3.4 MoveUp: move the object identifiers up in the tree 36
3.5 MTObjects: the whole segmentation algorithm 37
4.1 The Berger algorithm 50
4.2 Parallel hierarchical queue max-tree algorithm 51
4.3 Flood: recursive root-to-leaf flooding approach 52
4.4 Connect: procedure to merge trees 53
4.5 Flood_pilot: build the *pilot* max-tree 58
4.6 KeepLowestLevelRoot: stricter definition of level root 59
4.7 Refinement: the parallel hybrid algorithm 61
6.1 CCAPS: create pattern spectrum in parallel 90
6.2 MaxTreePatSpectrum2D: compute the local 2D ps 90
8.1 ProcessTree: process the max-tree of cores 115
8.2 ComputeAttributes: compute attributes of the viscous components 115

Acknowledgements

At the beginning of January 2012, I drove from Darmstadt to my new place in Groningen. It was indeed quite a long and lonely driving, but also the start of a longer four-year journey in which I worked on many interesting topics and in which I met just as many interesting and awesome new friends and colleagues.

I would like to start by thanking my supervisor and friend Michael Wilkinson. You have been an essential guidance when I moved my first steps in the realm of Mathematical Morphology. Your enormous knowledge (so much that I have recently nicknamed you "Wilkipedia") and your prompt availability contributed to make my work progress at a faster pace and led to engaging conversations. I felt as a real privilege to work with you. Our shared interests in astronomy, travelling, fossil hunting, ethnic cooking, history and your joyful attitude were at the basis of interesting coffee breaks and pleasant trips when attending conferences together. I must confess, though, that I never understood the rules of cricket, that you tried to explain to me so many times.

At first, I was a bit scared by having to deal with topics of astronomy, being new to the field. I want to thank my other supervisor Scott Trager from the Kapteyn Astronomical Institute for making me feel at ease since the beginning with clear explanations of previous findings and expert comments on the topics I worked on.

I am thankful to my promotor Nicolai Petkov for contributing to my personal and scientific growth, agreeing on all the courses, summer schools and conferences that I wanted to attend. Particularly, thanks to the "international workshops" that he organised, I gained confidence in presenting my work and I had the opportunity to meet many reputed scientists in an informal setting.

I would like to express my gratitude to the members of the assessment committee, the professors Scott Acton, Jos Roerdink and Philippe Salembier for their useful suggestions and valuable comments. It is funny to remember that precisely a journal paper by Salembier was the first article that I read on my very first day as a PhD.

I have been involved in some collaborations throughout my doctoral studies and I learned a lot by the interaction with professors, PhD colleagues and students. I would like to mention Georgios Ouzounis, Martino Pesaresi, Thijs van der

Hulst, Davide Punzo, Nadine Giese and the students Christiaan Arnoldus and Paul Teeninga. My thesis would have looked much less interesting without their contribution. I feel fortunate by having shared the academic environment with great scientists and nice colleagues: Michael Biehl, Paris Avgeriou, Marco Aiello, Doina Bucur, Mircea Lungu, the talks that you either held or organised and our conversations together were of inspiration to expand my horizons in many fields, also non-scientific. I would like to thank the university staff: Esmee Elshof, Desiree Hansen and Ineke Schelhaas, you have always been a support when I had to deal with bureaucracy and paperwork. I also thank Janieta de Jong for making the PhD progress meetings run as smooth as possible.

When I moved to The Netherlands, Groningen was not an unknown city to me: I knew already many people, friends and colleagues of my fiancée Tiziana. Céline, Mathieu, Felix, Julia, Miriam, Francesca, Claudia, Séb, Pat, Massimo, Matea, Krzyś, Johnny, with the more recent addition of Richard, Elena, Yagiz, Alwin and Jonas, how can I ever forget all the dinners, movie nights, football matches, gliding experiences, pub quizzes, funny and tiresome phd-movie makings, parties, Star Wars marathons and the juicy raclettes we had together in the last five years! I would like to tell my Indian friends Milon, Kiran, Suresh, Asish and Reema that it was amazing to get to know you and your culture both in The Netherlands and in India and host some of you in Italy. I can say that my discovery of Indian food was an unexpected and tasty surprise - and that is quite a compliment coming from an Italian.

At least once per week, I managed to overcome my laziness and go to play football. Many are the friends to remember, Dario, Riccardo, Marco, Alessandro, Diego, Francesco Pinto, Stephan with a honourable mention for "presidente" Francesco Mecozzi, the organiser of every match and, most importantly, a true friend and the best actor in my long-standing activity as editor of promotion phd-movies.

I am happy for the dear colleagues and friends that I met at the institute, in many cases sharing the same office. Baris, Ernest Mwebaze, Fred Kiwanuka, Andreas Neocleous (office mate and also flat mate for one year), Astone and Jiapan Guo (colleagues and athletes in the swimming pool), Laura Fiorini, the Spaniards Laura, Miguel, Manuel and Estefanía, the Brazilians Danilo, Daniel and Renata, George and Charmaine, Fritz, Fatimah, Petra, Mohammed Babai, Spyros, Christian, Sofia and the whole lot of Italian students from the University of Salerno, Walter, Vincenzo, Francesco, Nicola, Ilario, Raffaele, Peppe, Marco, we shared so many hours every day at the university, lunches, parties, coffees, road trips, conferences, house warming parties, cocktails, kart-racing, bike trips, beers and dinners with recipes from all around the world that in no way I can summarise everything in a few lines: just numbering your nationalities, I sum up to twelve or more different countries. You can all be sure that you have a special place in my heart and I cannot help but break into a smile whenever I remember all the things we did together. I want to thank also the colleagues "from the fourth floor", Jasper, André and Matthew, re-

membering the conferences attended together and our lunches at the canteen in the first months of my PhD.

I want to give a heartfelt thanks to my paranymphs Nicola and Massimo: you both have been there since the very beginning. Nicola, I can say that I grew up as a scientist together with you, since you began the Erasmus in Groningen soon after I started. I will keep on studying the Neapolitan language, I promise. Massimo, both your spontaneity and your cooking skills made me feel like still in Italy. I will miss our time in Groningen and our coffee breaks at work. I send a big hug to your family, Anna, Nora and Corinna.

I would like to thank my Italian best friends Domi, Giacomo, Tommy, Robbi and the other expat Alessio, because every time I go back home, we meet up and it feels like I never left. A big hug (and of course a brotherly punch) goes to my brother Francesco, for all the fun we have together and for your capability to minimize problems that I sometimes tend to exaggerate. Mando anche un grande abbraccio a mamma, a babbo, agli zii Angela e Ale e a Nonna Vera, che mi hanno aiutato ogni giorno con consigli e trucchetti su ricette da cucinare, come pulire la casa, far funzionare le lavatrici, consigli finanziari e molto, molto altro. Hanno pure installato Whatsapp e Skype per starmi piu vicino. Ringrazio tantissimo anche Franca per avermi fatto sempre trovare un confortevolissimo posto per dormire e ottime cene al suo "ristorante".

The biggest hug goes to my fiancée Tiziana. Our PhD studies crossed for about three years and it was great to finally live together in the same city and in the same house. Without you, I would not be the person I am now: thank you for encouraging me, long before this PhD experience, to pursue my dreams, even if that meant many times being far apart in different countries. Laughing together with you is one of those magic moments that Science alone will never be able to explain.

Ugo Moschini
Groningen
April 13, 2016