

**MASSIMO FORNASIER****Contents**

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## 1 Personal Data

*Name* : Massimo  
*Family name* : Fornasier  
*Birthday* : July 6 1975  
*Place of birth* : Feltre (BL), Italy  
*Marital status* : single, no kids  
*Academic degree* : Univ.-Doz. Dott. Ric. Dott.  
*Citizenship* : Italian

*Current Office* : \* Permanent *Senior Research Scientist*  
\* Leader of the group of *Analysis of Partial Differential Equations*  
\* Leader of the group of the START project “Sparse Approximation and Optimization in High-Dimensions”

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## 2 Presentation

### 2.1 Academic career in short

I was a doctoral student in Computational Mathematics at the University of Padua in Italy (1999-2002), under the joint supervision of Prof. Hans G. Feichtinger (Institute for Mathematics, University of Vienna, Austria) and Prof. Maria Morandi Cecchi (Department of Pure and Applied Mathematics, University of Padua, Italy). In the period 1998-2004 I was co-author together with Prof. Domenico Toniolo (Department of Physics “Galileo Galilei”) and scientific responsible of the Mantegna Project, i.e., the complete (mathematics based and computer assisted) restoration of the famous Andrea Mantegna’s frescoes in Padua (Italy) destroyed by a bombing in World War II<sup>1</sup>. I was awarded a scientific prize by the University of Padua for “A scientific work on the computer restoration of the fragments of the art frescoes in the Eremitani’s Church in Padua”. After the doctoral studies, I joined the EU-Research Training Network HASSIP (Harmonic Analysis and Statistics for Signal and Image Processing HPRN-CT-2002-00285), with PostDoc positions at the University of Vienna, Austria, University of Bremen, and University of Marburg, Germany (2003-2004). Later I obtained an Intra-European Individual Marie Curie Fellowship, project *Flexible Time-Frequency Decompositions and Adaptive Treatment of Operator Equations by Frames* (FTFDORF), at the University of Vienna (2004-2006). During the period 2003-2006 I also cooperated with the University of Rome “La Sapienza” on the basis of a local research grant. I joined RICAM (the Johann Radon Institute for Computational and Applied Mathematics, Austrian Academy of Sciences, Linz, Austria) in June 2006 and, with an unpaid leave of one year, I started in Oct. 2006 a cooperation within the Program in Applied and Computational Mathematics (PACM), Princeton University, U.S.A., on the basis of a second individual project *Sparse Approximation for Blind Source Separation* (SPARSE), an Outgoing International Marie Curie Fellowship. A further major project was approved in Nov. 2006: WWTF “Five Senses - Call 2006”, *Mathematical Methods for Image Analysis and Processing in Visual Arts*. In October 2007, I returned to RICAM. In June 2008 I obtained the Habilitation (venia docendi) at the University of Vienna. In November 2008 I have been awarded the START-Preis of the Fonds zur Förderung der wissenschaftlichen Forschung, Austria for the project “Sparse Approximation and Optimization in High Dimensions”. Since January 2009 I’m co-leader of the group of Analysis of PDEs at RICAM, and since April 2009 I’m coordinating the research team of the START project. In April 2009 I have been awarded the scientific prize “Prix de Boelpaep” of the Royal Academy of Sciences of Belgium for my work in mathematical imaging. In the period October-November 2009 I covered an invited visiting position at the Texas A&M University in College Station, Texas, U.S.A. On February 26 2010 I received a call for a W2 Professorship in Numerics for Partial Differential Equations/Scientific Computing from the University of Bonn (Germany), later declined. On April 14 2010 I received the “Best Paper Award” of the Austrian Academy of Sciences. On April 14 2010 my position at RICAM was made permanent. In the period March-May 2010 I covered a visiting Professor position at the University of Vienna (Austria). In July 2010 I have been granted a Heisenberg Professorship from the Deutsche Forschungsgemeinschaft (DFG) in Germany<sup>2</sup>. This Programme is a start-up co-financing for a Chair in Numerical Analysis at the Philipps-University of Marburg in Germany.

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<sup>1</sup><http://www.progettomantegna.it>

<sup>2</sup>[http://www.dfg.de/en/research\\_funding/programmes/individual/heisenberg/in\\_brief/index.html](http://www.dfg.de/en/research_funding/programmes/individual/heisenberg/in_brief/index.html)

### 3 Curriculum Vitae

#### 3.1 Education and academic degrees

**Habilitation (venia docendi)**

Habilitationsschrift title: *Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems*

Faculty of Mathematics,

University of Vienna, Austria

June 4, 2008

**Doctoral degree in Computational Mathematics**

Dissertation Title: *Constructive Methods for Numerical Applications in Signal Processing and Homogenization Problems*

no grades are provided in Italy

University of Padua (Italy), February 17 2003

Advisors: Prof. Dr. Hans Georg Feichtinger, Prof. Dr. Maria Morandi Cecchi

**Graduate Programme in Computational Mathematics**

University of Padua, Italy

Nov. 1999 – Dec. 2002

**Laurea in Mathematics**

Graduated *Magna cum Laude*

University of Padua, Italy

October 28 1999

**Studies in Mathematics**

University of Padua, Italy

Nov. 1994 – Oct. 1999

#### 3.2 Academic positions

**Visiting Professor**

Faculty of Mathematics

University of Vienna, Austria.

March – May 2010

**Visiting Scholar**

Department of Mathematics

Texas A&M University, U.S.A.,

October – December 2009

**Leader of the FWF START-Project**

“Sparse Approximation and Optimization in High-Dimensions”

Johann Radon Institute for Computational and Applied Mathematics

Austrian Academy of Sciences, Austria.

April 2009 – March 2015

**Leader of the Group of Analysis of Partial Differential Equations**

(jointly with Peter A. Markowich) Johann Radon Institute for Computational and Applied Mathematics  
Austrian Academy of Sciences, Austria.  
January 2009 – present time

**Senior Research Scientist**

(tenured position since April 2010)  
Johann Radon Institute for Computational and Applied Mathematics  
Austrian Academy of Sciences, Austria.  
June 2006 – present time

**Research Associate**

Program in Applied and Computational Mathematics  
Princeton University, U.S.A.  
October 2006 – October 2007

**Individual Marie Curie Fellow**

Faculty of Mathematics  
University of Vienna, Austria  
May 2004 – April 2006

**Research Assistant**

Department of Mathematical Methods and Models for Applied Sciences  
University of Rome “La Sapienza”, Italy  
June 2003 – May 2006

**Research Assistant (Marie Curie Fellow)**

EU-network RTN HASSIP (Harmonic Analysis and Statistics for  
Signal and Image Processing, contract HPRN-CT-2002-00285)  
Faculty of Mathematics  
University of Vienna, Austria  
January 2004 – April 2004

**Research Assistant (Marie Curie Fellow)**

EU-network RTN HASSIP (Harmonic Analysis and Statistics for  
Signal and Image Processing, contract HPRN-CT-2002-00285)  
AG Numerik/Wavelet Analysis Group – Zentrum für TechnoMathematik  
University of Marburg and University of Bremen, Germany  
July 2003 – December 2003

**Research Assistant (Marie Curie Fellow)**

EU-network RTN HASSIP (Harmonic Analysis and Statistics for  
Signal and Image Processing, contract HPRN-CT-2002-00285)  
Faculty of Mathematics  
University of Vienna, Austria  
May 2003 – June 2003

**Research Assistant (Österreich-Stipendium/Austrian Scholarship)**

Faculty of Mathematics  
University of Vienna, Austria  
November 2002 – April 2003

**Doctoral student** Graduate Program in Computational Mathematics

University of Padua, Italy  
November 1999 – October 2002

### **3.3 Other invited research visits**

#### **Max-Planck Institute for Mathematical Sciences**

Leipzig, Germany  
June 22-24 2009

#### **Department of Mathematics and Scientific Computing**

University of Graz, Austria,  
Feb. 26-28 2009

#### **Institute for Numerical Simulation**

University of Bonn, Germany,  
Feb. 8-13 2009

#### **Program in Applied and Computational Mathematics**

Princeton University, U.S.A.  
Oct. 15-27, 2008, Oct.-Dec. 2009

#### **Department of Mathematics**

University of Pavia, Italy  
May 21-22, Nov. 23-26 2008

#### **School of Mathematics**

University of Edinburgh, UK  
Feb. 27 - Mar. 5 2008

#### **Department of Applied Mathematics and Theoretical Physics**

Center of Mathematical Sciences  
Cambridge University, UK  
Nov. 21-30 2007, Mar. 6-12, Nov. 17-23 2008, April 19-23 2009

#### **Courant Institute of Mathematical Sciences**

New York University, U.S.A.  
Feb. 6-8,12,19-20,22,27, Mar. 21, Apr. 27,30, May 22 2007.

#### **AG Numerik/Wavelet-Analysis Group,**

Fachbereich Mathematik und Informatik der  
Philipps-Universitaet Marburg, Germany  
Mar .8-12 2004, Jun. 23-26 2004, Aug. 16-27 2004,  
Mar. 6-16 2005, Jan. 16-20 2006, Sept. 24-20 2006,  
Mar. 23-30 2008, Aug. 18-29 2008, Aug. 7-14 2009.

### **3.4 Other contracts and cooperations**

#### **Consulting contract** (project: FWF Operatoren fuer Zeit-Frequenz Analysis)

Faculty of Mathematics  
University of Vienna, Austria  
November 2002 – April 2003

**Cooperation pro bono publico** (Mantegna Project)

Conception and realization of the Mantegna Project, the mathematical and computer assisted restoration of Mantegnas art frescoes in the Eremitani Church in Padua ([www.progettomantegna.it](http://www.progettomantegna.it))

Mantegna Project Lab.

University of Padua, Italy

Dec. 1999 – present time

### 3.5 Individual honors and awards

**166 citations from 113 authors** on Mathematical Reviews and c.a. **620 citations** on Google Scholar, August 2010

**Heisenberg Professoship** (Deutsche Forschungsgemeinschaft), a start-up co-financing for a Chair in Numerical Analysis at the Philipps-University of Marburg in Germany.

**Best Paper Award** (Jubiläumsfonds der Stadt Wien für die ÖAW 2009) for the paper *Iteratively re-weighted least squares minimization for sparse recovery* (with I. Daubechies, R. DeVore, C. S. Güntürk), Commun. Pure Appl. Math., Vol. 63, no. 1, 2010, pp. 1-38

**Scientific prize “Prix de Boelpaepe” of the Académie Royale de Belgique – Classe des Sciences**, April 4 2009

<http://www.ricam.oeaw.ac.at/people/page/fornasier/PrixDeBoelpaepe.pdf>

<http://www2.academieroyale.be/academie/documents/CONCOURS/PRIXETSUBVENTIONSInformati697.pdf>

**The paper** *Restoration of color images by vector valued BV functions and variational calculus* (with R. March), SIAM J. Appl. Math., Vol. 68 No. 2, 2007, pp. 437-460 is used by SIAM (Society for Industrial and Applied Mathematics in the U.S.A.) as a relevant example of applicable mathematics:

<http://www.siam.org/publicawareness/images.php>

**FWF-START award 2008** for the project “Sparse Approximation and Optimization in High-Dimensions” ([http://www.fwf.ac.at/de/public\\_relations/press/pa20081110.html](http://www.fwf.ac.at/de/public_relations/press/pa20081110.html))

**Finalist (among the best 4 candidates) for the scientific prize** “Young researchers in Mathematics competition”, University of Padua, 2007

(<http://www.ricam.oeaw.ac.at/people/page/fornasier/finalPD.pdf>)

**Scientific prize** for “A scientific work on the computer restoration of the fragments of the art frescoes in the Eremitanis Church in Padua”, University of Padua, Italy, 1999

**Marie Curie Outgoing International Fellowship** (contract MOIF-CT-2006-039438, 18 months) of the European Commission (6th Framework Programme) project “Sparse Approximation for Blind Source Separation”, 2006

**Individual Marie Curie Fellowship** (contract MEIF-CT-2004-501018, 2 years) of the European Commission (6th Framework Programme) project “Flexible Time-Frequency Decompositions and Adaptive Treatment of Operator Equations by Frames”, 2004

**Research fellowship** (assegno di ricerca, 3 years) “Wavelets and frames in approximation theory”, University of Rome “La Sapienza”, Italy, 2003

**Austrian scholarship** (Österreich-Stipendium, 6 months) of the Federal Ministry for Education, Science, and Culture (BMBWK) via ÖAD (Österreichischer Austauschdienst) and the Ministero degli Esteri Ital-

iano (the Italian Ministry of Foreign Affairs), Austria, 2002

**Doctoral Studies Scholarship** (3 years) of the University of Padua, Italy, 1999

### 3.6 Recent invitations and offers for Professorships at international Universities

**Heisenberg Professorship** for a Chair in Numerical Analysis and Computational Harmonic Analysis at the Philipps-University of Marburg, Germany, 2010 (under negotiation)

**Offer for a W2-professor position** in Scientific Computing/Numerical Simulation at the University of Bonn, Germany, 2010 (declined)

**Visiting Professor position** at the University of Vienna, Austria, 2010

**Visiting Professor position** at the University of Provence in Marseille, France, 2010 (declined)

**Offer for a W1-professor position** in Numerical Fourier Analysis at the University of Rostock, Germany, 2008 (declined)

### 3.7 Research publications

<i>Scientific production</i>	:	Dissertations	:	3
	:	Papers in refereed journals	:	30
	:	Submitted papers	:	4
	:	Papers in preparation	:	1
	:	Papers in proceedings	:	10
	:	Book chapters	:	5
	:	Books	:	1
	:	Lecture notes	:	1
	:	Internal manuscripts	:	3

#### 3.7.1 Preprints

1. *Low rank matrix recovery via iteratively reweighted least squares minimization* (with H. Rauhut and R. Ward), preprint, 2010.

#### 3.7.2 Submitted preprints to refereed journals

2. *Learning functions of few arbitrary linear parameters in high dimensions* (with K. Schnass and J. Vybiral), submitted to Found. Comput. Math., August 2010, 31 pp.

3. *Existence of minimizers of the Mumford and Shah functional with singular operators in two space dimensions* (with R. March), submitted to SIAM J. Math. Anal., March 2010, 27 pp.

4. *Fluid dynamic description of flocking via Povzner-Boltzmann equation* (with J. Haskovec and G. Toscani), submitted to Physica D (nonlinear phenomena), Dec. 2009, 19 pp.

5. *Multilevel preconditioning for adaptive sparse optimization* (with S. Dahlke and T. Raasch), submitted to Math. Comput., Aug. 2009, 49 pp.

#### 3.7.3 Refereed journal papers

6. *A convergent overlapping domain decomposition method for total variation minimization* (with A. Langer and C.-B. Schönlieb), to appear in Numer. Math., 2010, 35 pp.

7. *A kinetic flocking model with diffusion* (with R. Duan and G. Toscani), to appear in *Commun. Math. Phys.*, 2010, 44 pp.
8. *Asymptotic flocking dynamics for the kinetic Cucker-Smale model* (with J. A. Carrillo, J. Rosado, and G. Toscani), *SIAM J. Math. Anal.*, Vol. 42, no. 1, 2010, pp. 218-236
9. *Iterative thresholding meets free-discontinuity problems* (with R. Ward), to appear in *Found. Comput. Math.*, 2010, 49 pp.
10. *Subspace correction methods for total variation and  $\ell_1$ -minimization*, (with C.-B. Schönlieb), *SIAM J. Numer. Anal.*, Vol. 47, no. 5, 2009, pp. 3397-3428
11. *Optimal adaptive computation in the Jaffard algebra and localized frames* (with S. Dahlke and K. Gröchenig), *J. Approx. Theory*, Vol. 162, no. 1, 2010, pp. 153-185.
12. *Iteratively re-weighted least squares minimization for sparse recovery* (with I. Daubechies, R. DeVore, C. S. Güntürk), *Commun. Pure Appl. Math.*, Vol. 63, no. 1, 2010, pp. 1-38
13. *The application of joint sparsity and total variation minimization algorithms to a real-life art restoration problem* (with R. Ramlau and G. Teschke), *Adv. Comput. Math.*, Vol. 31, Nos 1-3, 2009, pp. 301-329.
14. *Nonlinear and adaptive frame approximation schemes for elliptic PDEs: theory and numerical experiments* (with S. Dahlke, M. Primbs, T. Raasch, M. Werner), *Numerical Methods for Partial Differential Equations*, Vol. 25, no. 6, 2009, pp. 1366-1401
15. *Iterative thresholding algorithms* (with H. Rauhut), *Appl. Comput. Harmon. Anal.*, Vol. 25, No. 2, 2008, pp. 187-208.
16. *Adaptive frame methods for nonlinear variational problems* (with M. Charina and C. Conti), *Numer. Math.*, Vol. 109 No. 1, 2008, pp. 45-75.
17. *Domain decomposition methods for linear inverse problems with sparsity constraints*, *Inverse Problems*, Vol. 23, No. 6, 2007, pp. 2505-2526.
18. *Accelerated projected gradient method for linear inverse problems with sparsity constraints* (with I. Daubechies and I. Loris), *J. Fourier Anal. Appl.*, Vol. 14, No. 5-6, 2008, pp. 764-792.
19. *Recovery algorithms for vector valued data with joint sparsity constraints* (with H. Rauhut), *SIAM J. Numer. Anal.*, vol. 46, No. 2, 2008, pp. 577-613.
20. *Restoration of color images by vector valued BV functions and variational calculus* (with R. March), *SIAM J. Appl. Math.*, Vol. 68 No. 2, 2007, pp. 437-460.
21. *Adaptive iterative thresholding algorithms for magnetoencephalography (MEG)* (with F. Pitolli), *J. Comput. Appl. Math.*, Vol. 221 No. 2, 2008, pp. 386-395
22. *Sampling theorems on bounded domains* (with L. Gori), *J. Comput. Appl. Math.*, Vol. 221 No. 2, 2008, pp. 376-385.
23. *Generalized coorbit theory, Banach frames, and the relation to  $\alpha$ -modulation spaces* (with S. Dahlke, H. Rauhut, G. Steidl, and G. Teschke), *Proc. London Math. Soc.*, Vol. 6 No. 2, 2008, pp. 464-506.
24. *Adaptive frame methods for elliptic operator equations: the steepest descent approach* (with S. Dahlke, T. Raasch, R. Stevenson and M. Werner), *IMA J. Numer. Anal.*, Vol. 27 No. 4, 2007, pp. 717-740
25. *Banach frames for  $\alpha$ -modulation spaces*, *Appl. Comp. Harmon. Anal.*, Vol. 22, No. 2, 2007, pp. 157-175.
26. *Adaptive frame methods for elliptic operator equations*, (with S. Dahlke and T. Raasch) *Adv. Comp. Math.*, Vol. 27 No. 1, 2007, pp. 2763
27. *On some stability results of localized atomic decompositions*, *Rend. Mat. Appl.*, No. 26, 2006, pp. 315-325.
28. *Nonlinear projection recovery in digital inpainting for color image restoration*, *J. Math. Imaging Vis.* Vol. 24, No. 3, 2006, pp. 359-373.
29. *Flexible Gabor-wavelet atomic decompositions for  $L^2$  Sobolev spaces* (with H. G. Feichtinger), *Ann. Mat. Pura Appl.* Vol. 185(4), No. 1, 2006, pp. 105-131.
30. *Continuous frames, function spaces, and the discretization problem* (with H. Rauhut), *J. Fourier Anal. Appl.*, Vol. 11, No. 3, 2005, pp. 245-287.
31. *Intrinsic localization of frames* (with K. Gröchenig), *Constr. Approx.*, Vol. 22, No. 3, 2005, pp. 395-415.

32. *Fast homogenization algorithm based on asymptotic theory and multiscale schemes* (with M. Morandi Cecchi), Numer. Algorithms, Vol. 40, No. 2, 2005, pp. 171-186
33. *Fast, robust, and efficient 2D pattern recognition for re-assembling fragmented images* (with D. Toniolo), Pattern Recognition, Vol. 38, No. 11, 2005, pp. 2074-2087.
34. *Quasi-orthogonal decompositions of structured frames*, J. Math. Anal. Appl. Vol. 289, No. 1, 2004, pp. 180-199.
35. *Function spaces inclusions and rate of convergence of Riemann-type sums in numerical integration*, Numer. Funct. Anal. Opt., Vol. 24, Nos. 1 & 2, 2003, pp. 45-57.

### 3.7.4 Conference papers

36. *Mathematical methods for spectral image reconstruction* (with W. Baatz and J. Haskovec), Proceedings of the workshop Scientific Computing for Cultural Heritage, Heidelberg Germany, November 2009.
37. *Binary based fresco restoration* (with W. Baatz, P. Markowich, and C.-B. Schnlieb), Proceedings of the conference Bridge 2009: Mathematics, Music, Art, Architecture, Culture, pp. 337-338
38. *Compressive Algorithms. Adaptive Solutions of PDE's and Variational Problems*, invited lecture for the IMA Mathematics of Surfaces XIII conference, 2009
39. *Electric current density imaging via an accelerated iterative algorithm with joint sparsity constraints* (with G. Bretti and F. Pitolli), SPARS'09 - Signal Processing with Adaptive Sparse Structured Representations (2009)
40. *Domain decomposition methods for compressed sensing* (with A. Langer and C.-B. Schönlieb), Proc. Int. Conf. SampTA09, Marseilles, 2009
41. *Mathematics enters the picture*, Proceedings of the workshop MathKnow 2008, Springer, 2009
42. *Iteratively re-weighted least squares minimization: proof of faster than linear rate for sparse recovery* (with I. Daubechies, R. DeVore, and C. S. Güntürk), Information Sciences and Systems, 2008. CISS 2008. 42nd Annual Conference, pp. 26-29
43. *Inpainting of ancient Austrian frescoes* (with W. Baatz, C.-B. Schönlieb, and P. Markowich), Conference proceedings of Bridges 2008, Leeuwarden 2008, pp.150-156.
44. *Faithful recovery of vector valued functions from incomplete data. Recolorization and art restoration*, Lecture Notes in Computer Science, Volume 4485/2007, Proceedings of the First International Conference on Scale Space Methods and Variational Methods in Computer Vision (Sgallari, Fiorella; Murli, Almerico; Paragios, Nikos Eds.), 2007, pp. 116-127.
45. *On elementary sampling theorems on bounded domains* (with L. Gori), Proc. Int. Conf. ICNAAM 2005 (Ed. Simos Theodore S. et al.), Weinheim: Wiley-VHC, pp. 619-623.
46. *Building a bridge between Gabor and wavelet worlds*, Mini-Workshop: Wavelets and Frames, Feb. 15-21 2004, Oberwolfach Reports, 1(1), 2004, pp. 490-494.
47. *Decompositions of Hilbert spaces: local construction of global frames*, Proc. Int. Conf. Constructive Function theory 2002, Varna, DARBA, Sofia, 2003, pp. 275-281.

### 3.7.5 Book chapters

48. *Particle, Kinetic, Hydrodynamic Models of Swarming* (with J. A. Carrillo, G. Toscani, and F. Vecil), within the book "Mathematical modeling of collective behavior in socio-economic and life-sciences", Birkhäuser (in preparation, Eds. Lorenzo Pareschi, Giovanni Naldi, and Giuseppe Toscani), 2010, 34 pp.
49. *Numerical Methods for Sparse Recovery* within the book "Theoretical Foundations and Numerical Methods for Sparse Recovery", Radon Series in Applied and Computational Mathematics, de Gruyter (Ed. Massimo Fornasier), 2010, 110 pp.
50. *Compressive Sensing* (with Holger Rauhut) in the "Handbook of Mathematical Methods in Imaging", Springer 2010 (<http://refworks.springer.com/mrw/index.php?id=2420>)
51. *Il Progetto Mantegna: storia e risultati* (Italian) (with R. Cazzato, G. Costa, A. Dal Farra, D. Toniolo, D. Tosato, C. Zanuso), in Andrea Mantegna. La Cappella Ovetari a Padova (Anna Maria Spiazzi, Alberta De Nicolò Salmazo, Domenico Toniolo eds.), Skira, 2006.

52. *Computer-based re-composition of the frescoes in the Ovetari Chapel in the Church of the Eremitani in Padua. Methodology and initial results*, (Italian/English) (with D. Toniolo), in “Mantegna nella chiesa degli Eremitani a Padova. Il recupero possibile” Ed. Skira, May 2003, pp. 15-23.

### 3.7.6 Books

53. *Theoretical Foundations and Numerical Methods for Sparse Recovery*, Radon Series in Applied and Computational Mathematics, de Gruyter, July 2010  
(<http://www.degruyter.de/cont/fb/ma/detail.cfm?isbn=9783110226140&sel=pi>)

### 3.7.7 Dissertations

54. *Compressive Algorithms. Adaptive Solutions of PDE's and Variational Problems*, Habilitationsschrift, Faculty of Mathematics, University of Vienna, January 7, 2008, 426 pp.

55. *Constructive Methods for Numerical Applications in Signal Processing and Homogenization Problems*, doctoral thesis, University of Padua, Dec. 2002.

56. *Un metodo per la rappresentazione e il confronto di immagini a meno di rotazioni. Un contributo alla ricostruzione virtuale degli affreschi della Chiesa degli Eremitani in Padova* (Italian), Laurea thesis, Department of Pure and Applied Mathematics, University of Padua, Oct. 1999.

### 3.7.8 Lecture notes

57. *Introduzione all'analisi armonica numerica* (Italian), Lecture Notes, 2007 112 pp.

### 3.7.9 Miscellaneous

58. *Proposta per una anastilosi informatica degli affreschi della Capella Ovetari nella Chiesa degli Eremitani in Padova* (Italian) (with C. Fanin and D. Toniolo), technical report DFPD 02/EI/31, Department of Physics "G. Galilei", University of Padua.

59. *Compactly supported circular harmonics: fast, robust and efficient 2D pattern recognition*, (with D. Toniolo), technical report DFPD 02/EI/32, Department of Physics "G. Galilei", University of Padua.

60. *Una discussione matematica sulla rappresentazione ed il confronto di immagini a meno di rotazioni. Un contributo alla ricostruzione informatica degli affreschi nella Chiesa degli Eremitani in Padova* (Italian), technical report DFPD 99/EI/24, Department of Physics "G. Galilei", University of Padua.

## 3.8 Oral presentations

### 3.8.1 Plenary lectures

1. Compressive algorithms. Adaptive solutions of PDE's and variational problems, Int. Conf. Surfaces XIII, University of York, UK, September 7-9, 2009.

2. Compressive algorithms. Multilevel preconditioning and convergence rates, Int. Conf. Modern Methods of Time-Frequency Analysis, Strobl, Austria, June 15-20, 2009.

3. Variational principles and compressive algorithms, Int. Conf. "Mathematical Methods for Curves and Surfaces", Toensberg, Norway, June 26-July 1, 2008.

4. Mathematical imaging and visual art restoration, "SCCH 2007: Scientific Computing and the Cultural Heritage IWR Workshop", Heidelberger Akademie der Wissenschaften, Heidelberg, Germany, November 12-14, 2007.

### 3.8.2 Colloquia

5. Mathematics Enters the Picture. (The restoration of the Mantegna's frescoes in Padua), Kunsthistorische Gesellschaft, Institut für Kunstgeschichte, University of Vienna, May 26, 2010.

6. Compressed numerical methods for well-posed and degenerate elliptic PDEs, Department of Mathematics, Technical University of Munich, May 20, 2010
7. Innovative Sparse Recovery Methods for PDEs, Mathematical Colloquium, Department of Mathematics, University of Osnabrück, May 12, 2010
8. Compressed numerical methods for well-posed and degenerate elliptic PDEs, Seminar for Applied Mathematics, ETH-Zürich, April 12, 2010
9. Compressed numerical methods for well-posed and degenerate elliptic PDEs, Department of Mathematics, University of Basel, November 19 2009
10. Compressed numerical methods for well-posed and degenerate elliptic PDEs, Institut für Numerische und Angewandte Mathematik, University of Göttingen, October 31 2009
11. Compressed numerical methods for well-posed and degenerate elliptic PDEs, Institute for Numerical Simulation, University of Bonn, October 29, 2009
12. Sparse approximation and optimization in high dimensions, Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany, June 23, 2009.
13. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, Department of Mathematics and Computer Sciences, Technical University of Munich, Germany, June 2 2009.
14. Sparse Approximation and Optimization in High Dimensions, Faculty of Mathematics, University of Vienna, Austria, May 13 2009.
15. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, Center of Mathematics for Applications, University of Oslo, Norway, Apr. 16. 2009.
16. Innovative theories, methods, and applications in signal and image processing, IDIAP-EPFL, Lausanne, Switzerland, March 18, 2009
17. Variational principles and compressive algorithms, Department of Mathematics, University of Regensburg, Germany, October 1, 2008.
18. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, Seminar for Applied Mathematics, ETH-Zurich, Dec. 17. 2008.
19. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, Department of Mathematics, University of Leeds, UK, June 19, 2008.
20. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, Department of Mathematics, University of Rostock, Germany, June 18, 2008.
21. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, Habilitationskolloquium, Faculty of Mathematics, University of Vienna, Austria, June 4 2008.
22. Faithful recovery of vector valued functions from incomplete data. Recolorization and art restoration, Colloquium, Institut für Numerische und Angewandte Mathematik (NAM), Georg-August-Universität Göttingen, Göttingen, Germany, Dec. 19 2006.
23. Faithful recovery of vector valued functions from incomplete data. Recolorization and art restoration, Colloquium, Program in Applied and Computational Mathematics, Princeton University, Princeton, U.S.A., Nov. 20 2006.

### 3.8.3 Invited seminars at universities and research institutions

24. Mathematics enters the picture. An Italian touch on mathematical imaging, Center for Approximation Theory Seminar, Texas A&M University, U.S.A.
25. Efficient numerical methods for  $L_1$ -minimization, Numerical Analysis Seminar, Texas A&M University, U.S.A.
26. Special seminar: A Closer Look to Compressed Sensing, Sparse Recovery, and Generalizations, Department of Mathematics and Scientific Computing, University of Graz, Feb. 27, 2009
27. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, , Department of Mathematics and Scientific Computing, University of Graz, Feb. 26, 2009
28. Wavelets, joint sparsity, and image processing, FNRS Contact Group "Wavelets and applications", Universit libre de Bruxelles, Jan. 13, 2009.
29. Mathematics enters the picture, Department of Electronics and Informatics (ETRO), Vrije Universiteit Brussel, Jan. 13, 2009.

30. Mathematics enters the picture, Fraunhofer ITWM Bildverarbeitungsungen, Kaiserslautern, Jan. 12, 2009.
31. A kinetic model for flocking, Hong Kong City University, Dec. 11, 2008.
32. Compressive algorithms, variational principles, and free-discontinuity problems, Department of Mathematics, University of Rome “Tor Vergata”, September 23, 2008.
33.  $\ell_1$ -minimization in compressive algorithms for PDEs and variational problems, Department of Mathematics, University of Pavia, Italy, May. 22, 2008.
34. L'applicazione, architetto della matematica. La matematica, architetto di nuove applicazioni (The application, architect of mathematics. Mathematics, architect of new applications), Faculty of Engineering, University of Bologna, May 20, 2008.
35. Compressive Algorithms. Adaptive Solutions of PDEs and Variational Problems, (invited seminar for an Associate Professorship in Numerical Analysis), Institute for Numerical Simulation, University of Bonn, Germany, May 16 2008.
36. A comparison of joint sparsity and total variation minimization algorithms in a real-life art restoration problem, Centre de Mathematiques et de Leur Applications, CNRS and École Normale Supérieure de Cachan, France, May 15, 2008.
37. Domain decomposition methods for singular PDEs and applications in image processing, Laboratoire Jacques-Louis Lions, Université Pierre et Marie Curie, France, May 13, 2008.
38.  $\ell_1$ -minimization in compressive algorithms for PDEs and variational problems, Department of Mathematics, University of Milano, Italy, Apr. 22, 2008.
39. Iterative thresholding algorithms and acceleration methods, Department of Mathematics, Philipps-University of Marburg, Germany, Mar. 25, 2008.
40. Compressive algorithms, Numerical Analysis seminar, Department of Applied Mathematics and Theoretical Physics, Center of Mathematical Sciences (CMS) of the University of Cambridge, UK, Mar. 6, 2008.
41. Iterative re-weighted least square algorithms for compressed sensing, School of Mathematics, University of Edinburgh, UK, Mar. 3 2008.
42. Compressive algorithms, Department of Mathematics, University of York, UK, Feb. 29 2008.
43. Compressive algorithms and variational problems, Department of Mathematics, University of Trieste, Italy, Feb. 19, 2008
44. PDE methods in image processing, PDE group seminar, Radon Institute for Computational and Applied Mathematics, Linz, Austria, Jan. 28 2008.
45. Iterative thresholding algorithms for inverse problems with sparsity constraints, Harmonic Analysis and Signal Processing Seminar, Courant Institute of Mathematical Sciences, NY University, USA, April 30, 2007.
46. A unified approach to iterative thresholding algorithms for sparse recovery, Norbert Wiener Center Seminar, University of Maryland, College Park, USA, April 12, 2007.
47. Variational calculus, wavelets, and image processing, Radon Institute for Computational and Applied Mathematics (RICAM), Linz, Austria, Feb. 7 2006.
48. Tecniche di ricostruzione di segnali e di immagini digitali con metodi di interpolazione e variazionali con vincoli, Workshop “Modelli differenziali e tecniche numeriche nel trattamento delle immagini”, Department of Mathematics “Castelnuovo”, University of Rome “La Sapienza”, Apr. 15 2004.
49. Frame expansions for numerical analysis and signal/image processing. Applications in image pattern recognition and real world examples, “Graduiertenkolleg Angewandte Algorithmische Mathematik”, Technische Universität München, Zentrum Mathematik, Nov. 3 2003.
50. Introduzione alla teoria degli spazi coorbita quale interpretazione unificata delle decomposizioni di Gabor e wavelets e possibili estensioni, Department of Mathematics, University Bicocca in Milano, Jun. 10 2002.
51. Analisi tempo-frequenza e algoritmi di pattern matching nel 2D, Department of Mathematics, University of Verona, Jun. 5 2002.
52. Gabor-wavelet transform and discrete frames, Department of Mathematics, University of Udine, Oct. 19 2001.

53. Local construction of global frames and applications, Department of Mathematics, Technical University of Denmark, Lyngby, Denmark, August 6 2001.

54. Flexible Gabor-wavelet transforms and applications in PDEs and signal processing, Department of Pure and Applied Mathematics, University of Padua, July 12 2001.

55. Un metodo per la rappresentazione ed il confronto di immagini a meno di rotazioni. Un contributo alla ricostruzione virtuale degli affreschi della Chiesa degli Eremitani in Padova, Department of Pure and Applied Mathematics, University of Padua, March 13 2000.

### 3.8.4 Invited talks at conferences and workshops

56. Inverse free-discontinuity problems and iterative thresholding algorithms, Emerging Topics in Dynamical Systems and Partial Differential Equations - DSPDE's, Barcelona, May 31 - June 4 2010

57. Inverse free-discontinuity problems and iterative thresholding algorithms, SIAM Conference on Imaging Science (IS10), Chicago, U.S.A., April 12-14, 2010

58. Subspace correction methods for  $L_1$  and total variation minimization, SIAM Conference on Imaging Science (IS10), Chicago, U.S.A., April 12-14, 2010

59. Inverse free-discontinuity problems and iterative thresholding algorithms, AIP 2009, Vienna, July 21, 2009

60. Multilevel preconditioning in inverse problems with sparsity constraints, AIP 2009, Vienna, July 21, 2009

61. Inverse free-discontinuity problems and iterative thresholding algorithms EPSRC Symposium Capstone, Warwick Mathematical Institute, UK, June 30 – July 3, 2009.

62. Iterative thresholding: domain decompositions, multilevel preconditioning, and adaptivity, Tomography with Wavelets, Observatoire Océanologique, Villefranche-sur-Mer, France, May 28-30 2009.

63. A kinetic model of flocking, Workshop on Modern Topics in Nonlinear Kinetic Equations, University of Cambridge, UK, April 20-22, 2008.

64. Domain decomposition methods for total variation minimization, The Third International Conference on Scientific Computing and Partial Differential Equations at Hong Kong Baptist University, Hong Kong, Dec. 8-12, 2008.

65. Subspace decomposition method for very large scale sparse optimizations, Structured Decompositions and Efficient Algorithms, Dagstuhl Seminar, Germany, Nov. 30 – Dec. 5, 2008.

66. A kinetic model for flocking, Kinetic modelling for socio-economic and related problems, Vigevano, Italy, November 27-29, 2008.

67. Hot topics Workshop: Multi-Manifold Data Modeling and Applications, Institute for Mathematics and its Applications (IMA), University of Minnesota, U.S.A., October 27-30 2008.

68. Modern harmonic analysis and PDEs methods for visual art restoration, Modelling and Numerics for Monuments Conservation, University of Orleans, France, Sept. 4-5 2008.

69. Image and Signal Processing, Foundations of Computational Mathematics (FoCM08), Hong-Kong, China, Jun. 24-26, 2008.

70. Modern methods of harmonic analysis and PDEs in mathematical imaging, Mathknow08 - Mathematics, Applied Sciences, and Real Life, MOX - Technical University of Milan, Italy, May 23, 2008.

71. Inverse problems and sparsity measures, Minisymposium Inverse Problems with Sparsity Constraints, GAMM 2008, Bremen, Germany, Mar. 31 – Apr. 4, 2008.

72. Compressive algorithms: beyond adaptive wavelet methods in PDEs, Workshop on “Adaptive Numerical Methods for PDEs”, Wolfgang Pauli Institute, Vienna, Austria, Jan. 21-25 2008.

73. Mathematical tools in signal processing and sparse optimization, Co. ESTECO S.r.l. [www.esteco.com](http://www.esteco.com), Area Science Park, Trieste, Italy, December 14, 2007.

74. Evaluation of the project “Mathematical Methods for Image Analysis and Processing in the Visual Arts”, WWTF, Vienna, Austria, December 5 2007.

75. Mathematics and art restoration, Institut für Konservierung und Restaurierung, Akademie der bildenden Künste Wien, Vienna, Austria, November 9 2007.

76. von Neumann Symposium “Sparse Representation and High-Dimensional Geometry”, July 8-12, 2007

77. Recovery algorithms for vector valued data with joint sparsity constraints, Sparse Approximation Workshop, Nov. 10-12 2006, Princeton University, USA.

78. Frame adaptive methods for signal processing and operator equations, Workshop “Time-frequency analysis and stationary filtering”, BIRS, Banff, Canada, Sept. 24-29 2005.

79. Some applications of localization of frame theory, Mathematisches Forschungsinstitut Oberwolfach, Feb. 18 2004.

80. Proposta per una anastilosi informatica degli affreschi della Cappella Ovetari nella Chiesa degli Eremitani in Padova, Consiglio di amministrazione della Fondazione Cassa di Risparmio di Padova e Rovigo, July 21 2000.

### 3.8.5 Contributed conference presentations

81. Subspace correction methods in sparse optimization, Workshop “Inverse Problems in Medical Imaging”, Universitätszentrum Obergurgl, Austria, Jan. 22-27 2008.

82. Accelerated iterative thresholding algorithms, Conference on Applied Inverse Problems 2007: Theoretical and Computational Aspects, June 25-29, 2007.

83. Sparse recovery, free-discontinuity problems and image inpainting, Workshop on “PDEs and Variational Tools in Image Inpainting”, Wolfgang Pauli Institute, Vienna, Austria, June 11-13, 2007.

84. Faithful recovery of vector valued functions from incomplete data. Recolorization and art restoration, Scale Space Variational Methods 2007, Ischia, Italy, May 30 - June 2, 2007.

85. Fast reconstruction algorithm for sparse multivariate and vector valued data, 1st Dolomites workshop on constructive approximation and applications, Sept. 8-12 2006, Alba di Canazei, Italia. 86. Variational methods, inpainting, and art restoration, Int. Conf. “Nonlinear PDEs: Homogenization and Kinetic Equations”, Vienna, Austria, June 26-30 2006.

87. Linear inverse problems with joint sparsity constraints, Mini-workshop “Sparsity and Applications”, Radon Institute for Computational and Applied Mathematics (RICAM), Linz, Austria, June 21 2006.

88. Fast algorithms for inverse problems with joint sparsity constraints, Int. Conf. Recent Progress in Spline and Wavelet Approximation, University of Rome La Sapienza, June 14-16 2006.

89. Metodi di campionamento non uniforme e variazionali per il restauro di immagini, Convegno nazionale GNCS, Dipartimento di Matematica F. Enriques, University of Milano, 14-16 febbraio 2006.

90. Adaptive algorithms. Mobile digital signal transmission, Int. Conf. MathMod, Vienna, Austria, February 8-10 2006.

91. On elementary sampling theorems on bounded domains, Int. Conf. ICNAAM 2005, Rodos, Greece, Sept. 16-20 2005.

92. Int. Conf. SampTA2005, Sampling Theory and Applications, Samsun, Turkey, July 10-15 2005.

93. Frames, greedy algorithms, and operator equations, Special Semester “Modern Methods of Time-Frequency Analysis”, Third Workshop “Nonorthogonal expansions and greedy algorithms”, Erwin Schroedinger Institute, Vienna, Austria, June 6-11 2005.

94. Frames, greedy algorithms, and operator equations, Int. Conf. “Modern Methods of Time-Frequency Analysis”, Strobl, Austria, May 23-28 2005.

95. Image processing, greedy algorithms, and operator equations, HASSIP midterm meeting, Vienna, Austria, April 26-27 2005.

96. Adaptive frame methods for magnetohydrodynamic flows, MASCOT04 4th Meeting on Applied Scientific Computing and Tools (Grid generation, approximation, and visualization), Florence, Italy, Nov. 25-27 2004.

97. Frame decompositions in image processing: applications in art restoration, SIMAI 2004, Isola di San Servolo, Venice, Italy, Sept. 20-24 2004.

98. Construction of smooth (wavelet) frames and their applications, Int. Conf. Classical and New Approximation Spaces: Theory and Applications, Rome, Italy, Feb. 5-7 2004. 1. Interpolation of Banach spaces by means of Gabor-wavelet frames, Int. Conf. Wavelets and Splines, S. Petersburg, Russia, July 2-8 2003.

99. Flexible Gabor-wavelets decompositions for L2 Sobolev spaces, Int. Conf. SampTA2003, Sampling Theory and Applications, Strobl, Austria, May 2003.

100. Fast registration methods based on local circular harmonic frames and applications to art frescoes restoration, GAMM2003 (Conference of Gesellschaft fuer Angewandte Mathematik und Mechanik e. v. 2003), Abano Terme, Italy, 24-28 March 2003.

101. Fast homogenization algorithm based on asymptotic theory and multiscale schemes, GAMM2003 (Conference of Gesellschaft fuer Angewandte Mathematik und Mechanik e. v. 2003), Abano Terme, Italy, March 24-28 2003.

102. Flexible Gabor-wavelet continuous and discrete frames in alpha-modulation spaces, 2nd Int. Gabor Workshop, Vienna, Austria, Dec. 3-7 2002.

103. Generalized structured frame expansions: a bridge from Gabor to wavelet theory, kick-off meeting of the EU-network RTN HASSIP (Harmonic Analysis and Statistics for Signal and Image Processing) HPRN-CT-2002-00285, Department of Mathematics, University of Provence, Marseille, France, Nov. 14-16 2002.

104. Un algoritmo di omogeneizzazione veloce basato sulla teoria asintotica e su schemi multiscala, "Convegno nazionale di Analisi Numerica: stato dell'arte", Arcavacata di Rende, University of Calabria, Sept. 26-28 2002.

105. Decompositions of Hilbert spaces: local construction of global frames, Int. Conf. Constructive Function Theory, Varna, Bulgaria, June 19-23 2002.

### 3.8.6 Invited public lectures

106. Marie Curie International Fellowships, workshop on PEOPLE 4 YOU, BMWF – neue Medi-enräume, Vienna, Austria, May 13 2009.

107. Il Progetto Mantegna a Padova (The Mantegna Project in Padua), Conferenza Matematica e Cultura 2009, Auditorium Santa Margherita, University Ca Foscari of Venice, March 27, 2009.

108. Mathematics enters the picture, Interdisziplinäres Dialogforum (ID) – Kick-off, Senatssaal, University of Vienna, Dec. 4, 2008.

109. Matematica e applicazioni all'arte e alla tecnologia (Mathematics and applications in art and technology), presentation of the book "Matematici al lavoro" (Mathematicians at work), Department of Mathematics, University of Milano, Italy, Apr. 22, 2008.

110. Matematica e Arte (Mathematics and Art), Istituto Comprensivo di Correzzola, Comune di Candiana, Candiana, Italy, December 15, 2007.

111. Marie Curie Outgoing International Fellowship, workshop on PEOPLE & IDEAS - Projekte im 7. EU-Rahmenprogramm, Österreichische Akademie der Wissenschaften, Vienna, Austria, December 7 2007.

112. Il "Progetto Mantegna" a Padova e Sviluppi (The Mantegna Project in Padua and Developments), University for Adult People, Belluno, Italy, December 21 2006.

113. Presentazione nazionale del "Progetto Mantegna" (National presentation of the Mantegna Project), Salone Internazionale del Restauro, Fiera di Ferrara, Italy, Mar. 29 2001.

## 3.9 Teaching

### 3.9.1 Invited short courses

- Numerical methods for sparse recovery, 5 hour course, Summer School on "Theoretical Foundations and Numerical Methods for Sparse Recovery" held at the Johann Radon Institute for Computational and Applied Mathematics (RICAM), Linz - Austria, on August 31 - September 4, 2009
- Sparse recovery algorithms from exact and incomplete data, 6 hour course, Dolomites Research Week on Approximation 2007, Sept. 4-6 2007, University of Verona, Alba di Canazei, Italy.
- Mathematical modelling, 6 hour course, WS07-08 (January 7,14 2008), University of Vienna, Vienna, Austria.

### 3.9.2 Regular courses

- Calculus of variations and geometric measure theory, regular course, SS10, University of Vienna, Austria
- Project seminar Discontinuous Galerkin Method for Total Variation minimization attached to the course of Numerical Methods for Elliptic PDEs (Ulrich Langer), SS10, Johannes Kepler University, Linz, Austria
- Inverse problems in mathematical imaging, regular course, WS09-10, University of Padua, Italy
- Project seminar Discontinuous Galerkin Method for Total Variation minimization attached to the course of Numerical Methods for Elliptic PDEs (Ulrich Langer), SS09, Johannes Kepler University, Linz, Austria
- Recent advances in numerical harmonic analysis, regular course, SS08, University of Padua, Italy
- Variational methods for free-discontinuity problems and sparse recovery, special course, WS07-08, Johannes Kepler University, Linz, Austria
- Recent advances in numerical harmonic analysis, regular course, SS07, University of Padua, Italy
- Numerical analysis laboratory, assistant, SS06, University of Rome “La Sapienza”, Italy (large class at Engineering Fac.)
- Numerical analysis laboratory, assistant, SS05, University of Rome “La Sapienza”, Italy (large class at Engineering Fac.)
- Mathematics for signal and image processing, regular course, WS03-04, University of Padua, Italy
- Numerical harmonic analysis, regular course, WS02-03, University of Padua, Italy
- Calculus I, assistant, WS99-00, University of Padua, Italy (large class at Engineering Fac.)

### 3.10 Students

#### 3.10.1 Master students

Ilaria Patuzzi, February 2010 (co-supervisor Dr. Fabio Marcuzzi)

Laurea in Mathematics, University of Padua, Italy

Thesis (Italian) “Algoritmi di thresholding iterativo e riconoscimento della corrosione”

Grades: magna cum laude

Rocco Cazzato, October 2007 (co-supervisor Prof. Ruggero Frezza)

Laurea in Information Engineering, University of Padua, Italy

Thesis (Italian) “Un metodo per la ricolorazione di immagini e altri strumenti per il restauro - Il Progetto Mantegna e gli affreschi nella chiesa degli Eremitani”

Grades: best grades for an experimental thesis

Giulia Erica Valente, November 2006 (co-supervisor Dr. Fabio Marcuzzi)

Laurea in Mathematics, University of Padua, Italy

Thesis (Italian) “Gabor frames: teoria e algoritmi”

Grades: magna cum laude

### 3.10.2 Doctoral students

Andreas Langer

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

Feb. 2008 – present time

Thesis “Subspace Correction Methods for Total Variation Minimization”

Contribution to the supervision of the Ph.D. work of Rachel Ward (advisor Prof. Ingrid Daubechies, Program in Applied and Computational Mathematics, Princeton University, U.S.A., compare the paper [8]), and Carola-Bibiane Schönlieb (advisor Prof. Peter A. Markowich, Department of Applied Mathematics and Theoretical Physics (DAMTP), Centre for Mathematical Sciences, University of Cambridge, U.K., compare papers [6,9,37,40]).

### 3.10.3 PostDocs

#### Analysis of PDE group

Renjun Duan (Doctoral studies at City University Hong Kong)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

October 2008 – August 2010

Massimo Fonte (Doctoral studies at S.I.S.S.A., Trieste, Italy)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

April 2006 – March 2010

Francesco Vecil (Doctoral studies at the Autonomous University of Barcelona, Spain)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

October 2008 – September 2010

**START Project team** (<http://hdspare.ricam.oeaw.ac.at/>)

Jan Haskovec (Doctoral studies at the University of Vienna, Austria)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

July 2009 – June 2012

Yunho Kim (Doctoral studies at UC Los Angeles, U.S.A.)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

July – Sept. 2009

Karin Schnass (Doctoral studies at the Ecole Polytechnique Fédérale de Lausanne, Switzerland)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

January 2010 – June 2012

Jan Vybiral (Doctoral studies at the Friedrich-Schiller University of Jena, Germany)

Johann Radon Institute for Applied and Computational Mathematics, Austrian Academy of Sciences  
Linz, AUSTRIA

October 2009 – June 2012

### 3.11 Grants and external projects

**START award** (FWF - Fonds zur Förderung der wissenschaftlichen Forschung, Austria, 6 years)

Project title “Sparse Approximation and Optimization in High-Dimensions”

Submission date Feb. 22 2008, approval date Nov. 8 2008

PI: M. Fornasier

Apr. 2009 - Mar. 2015

Amount 1.137.860 EUR

**WWTF “Five Senses - Call 2006”** (4 years), Project Mathematical Methods for Image Analysis and Processing in Visual Arts

Nov. 2006 - Oct. 2010

PIs: W. Baatz, M. Fornasier, B. Kowanz, P. Markowich

Amount: 400.000 EUR

**Marie Curie Outgoing International Fellowship** (contract MOIF-CT-2006-039438, 18 months) of the European Commission (6th Framework Programme)

Project “Sparse Approximation for Blind Source Separation”

Oct. 2006 - March 2008

PI: M. Fornasier

Amount: 120.000 EUR

**Individual Marie Curie Fellowship** (contract MEIF-CT-2004-501018, 2 years) of the European Commission (6th Framework Programme)

Project “Flexible Time-Frequency Decompositions and Adaptive Treatment of Operator Equations by Frames”

May 2004 - April 2006

PI: M. Fornasier

Amount: 130.000 EUR

**Mantegna Project** [www.progettomantegna.it](http://www.progettomantegna.it) (3 years) Fondazione Cassa di Risparmio di Padova e Rovigo and University of Padua

Oct. 2001 - Sept. 2004

PIs: M. Fornasier and D. Toniolo

Amount: 525.000 EUR

### 3.12 Professional activities

#### 3.12.1 Journal reviewing

*Applied and Computational Harmonic Analysis, Computer Graphics Forum, Foundation of Computational Mathematics, IEEE Signal Processing Letters, IEEE Transaction on Image Processing, IMA Journal of Numerical Analysis, Inverse Problems, Journal of the American Mathematical Society, Journal of Computational and Applied Mathematics, Journal of Fourier Analysis and Applications, Journal of Functional Analysis, Journal of Function Spaces and Applications, Journal on Sampling Theory in Signal and Image Processing, Mathematische Nachrichten, Numerical Algorithms, Numerische Mathematik, SIAM Journal on Mathematical Analysis, SIAM Journal on Numerical Analysis.*

### 3.12.2 Conference, workshop, meeting organization

- 2011 Foundations of Computational Mathematics Conference, co-organizer (jointly with Martin Buhmann and Nira Dyn) of the minisymposium “Approximation theory”
- 2010 Workshop “Sparsity and Computation”, co-organizer (jointly with Ronald DeVore and Holger Rauhut), Hausdorff Center for Mathematics Bonn, June 7-11, 2010, Bonn, Germany
- 2010 Minisymposium “Particle and Mean Field Models for Flocking and Swarming” co-organizer (with Alethea Barbaro), Emerging Topics in Dynamical Systems and Partial Differential Equations DSPDEs’10, May 31 - June 4, 2010, Barcelona, Spain
- 2010 GAMM co-organizer (jointly with Micheal Hintermüller) of the session on Mathematical Imaging, March 22-26, 2010, Karlsruhe, Germany
- 2009 Summer School on “Theoretical Foundations and Numerical Methods for Sparse Recovery” held at the Johann Radon Institute for Computational and Applied Mathematics (RICAM), Linz - Austria, on August 31 - September 4, 2009 [http://www.ricam.oeaw.ac.at/events/summerschool\\_2009/](http://www.ricam.oeaw.ac.at/events/summerschool_2009/) (more than 70 confirmed students from 19 countries)
- 2009 Member of the Technical Program Committee for the Int. Conf. “Signal Processing with Adaptive Sparse/Structured Representations” (SPARS2009), Apr. 7-10 2009, Saint-Malo, France
- 2009 Special session “Sampling and (in)painting” at the Int. Conf. “Sampling Theory and Applications 2009” (SampTA 2009), Centre International de Rencontres Mathematiques (CIRM), May 28-22., 2009, Marseille-Luminy, France
- 2008 Minisymposium “Compressive algorithms for applied inverse problems with sparse solutions”, IX SIMAI - Società Italiana di Matematica Applicata e Industriale - Conference, September 15-19, 2008, Rome, Italy
- 2008 Thematic Programme “Applied Analysis and Fast Computation in Phase-Space”, September 2008, Wolfgang Pauli Institute, Vienna University, Austria
- 2007 Workshop “PDEs and Variational Tools in Image Inpainting” June 11-12 2007, Wolfgang Pauli Institute, Vienna University, Austria
- 2006 Mini-workshop “Sparsity and Applications”, June 21 2006, Johann Radon Institute for Computational and Applied Mathematics (RICAM), Austrian Academy of Sciences, Linz, Austria
- 2006 Int. Conference “Recent Progress in Spline and Wavelet Approximation”, June 14-16 2006, Rome, Italy
- 2004 Int. Conference “Classical and New Approximation Spaces: Theory and Applications”, Feb. 5-7 2004, Rome, Italy

## 4 The Research Activity

My main responsibility at the Johann Radon Institute for Computational and Applied Mathematics (RICAM) is the coordination of the group in “Analysis of Partial Differential Equations (PDEs)”. Within the scope of our group I currently focus on the topics reported below, which are involving the active cooperation of younger members of the group, Dr. Renjun Duan, Dipl. Ing. Andreas Langer, Dr. Jan Haskovec, and Dr. Francesco Vecil, as it is shown by the related joint publications. I emphasize below in particular the developments of my research which is characterized by the design of *Compressive Algorithms*, i.e., algorithms which recover, by nonlinear and adaptive iterations, the main features of a solution, in connection with sparse optimization techniques.

- (R1) **Variational calculus and geometric measure theory with particular emphasis on inverse free-discontinuity problems.** Free-discontinuity problems describe situations where the solution of interest is defined by a function and a lower dimensional set consisting of the discontinuities of the function [2]. Hence, the derivative of the solution is assumed to be a ‘small’ function almost everywhere except on sets where it concentrates as a singular measure. This is the case, for instance, in crack detection from fracture mechanics or in certain digital image segmentation and denoising problems. One of the best-known examples of free-discontinuity models is provided by the so-called Mumford-Shah functional [29] whose minimal solutions approximate a given datum and are smooth everywhere except on a minimal length surface. However, it is also of great practical interest to be able to recover functions which are piecewise smooth also from partial information, provided, for instance, by suitable linear measurements via a singular operator, i.e., an operator which is not necessarily boundedly invertible.

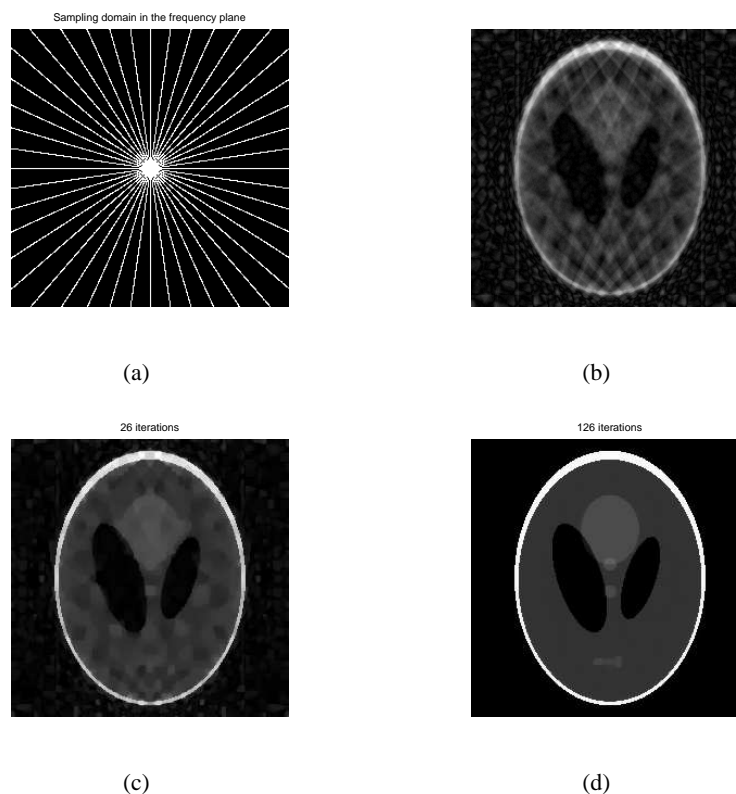


Figure 1: (a) Sampling data of the NMR image in the Fourier domain which corresponds to only 0.11% of all samples. (b) Reconstruction by backprojection. (c) Intermediate iteration of an efficient algorithm [28] for the recovery of the function. (d) The final reconstruction is exact.

An example from *nuclear magnetic resonance* (NMR) imaging may serve as an illustration. Here, the device scans a patient by taking 2D or 3D (incomplete) frequency measurements within a radial

geometry. Figure 1(a) describes such a sampling set of a 2D Fourier transform. Since a lengthy scanning procedure is very uncomfortable for the patient it is desirable to take only a minimal amount of measurements. As a recovery method we consider the minimization of a functional as mentioned above, formed by a term of discrepancy to partial Fourier transform data and a Mumford-Shah functional term. Such minimization can be addressed robustly, for instance, by means of iterative thresholding methods as introduced in [28]. For comparison, Figure 1(b) shows the recovery by a traditional backprojection algorithm. In Figures 1(c), 1(d) iterations of the algorithm in [28] are displayed. The final reconstruction in Figure 1(d) is surprisingly nearly exact which indicates the potential of Mumford-Shah regularization of performing as good results as total variation minimization in several sparse recovery problems, such as *compressed sensing* [3].

The theory of existence of minimal solutions in the *special bounded variation* (SBV) function space for the classical Mumford-Shah functional has been extensively explored [2]. The proof of existence of minimizers is based on a deep compactness result in SBV by Ambrosio [1], which requires  $L^\infty$  boundedness of solutions, typically obtained by truncation arguments when the datum is also assumed in  $L^\infty$ . However, despite its wide use in practice as a regularization method, as an alternative to total variation minimization [?, ?], not many theoretical results are currently available concerning Mumford-Shah functionals with singular operators modelling inverse problems.

In our recent work we seek for new existence results of minimal solutions for linear inverse problems, regularized with Mumford-Shah-like functionals. We search for such minimal solutions in a certain class of smooth functions out of piecewise Lipschitz continuous discontinuity sets. Differently from previous approaches we address linear problems on  $L^p$  and we do not try to obtain  $L^\infty$  boundedness in order to apply Ambrosio's results. Instead, we can resume compactness/coerciveness by exploiting the special structure of the linear measurements, geometrical and regularity properties of domains, interpolation inequalities, and classical compactness arguments in Sobolev spaces  $W^{1,p}$  [22].

Together with this theoretical analysis, we are addressing also numerical methods for computing such minimizers [28], and the analysis of the complexity of these algorithms. It is well-known (at least in the mono-dimensional case) that the computation of minimizers of free-discontinuity models *à la* Mumford-Shah can be executed directly with a  $O(N^3)$  algorithm. For inverse free-discontinuity problems as addressed in [22, 28], also in the mono-dimensional case, the minimization is shown to be NP-hard. The virtue of the algorithms proposed in [28] is to compute iteratively local minimizers (which will coincide with the global minimizer as soon as the starting point is close enough) in  $O(N)$  complexity.

- (R2) **Scalar conservation laws, Discontinuous Galerkin method, and stabilization via free-discontinuity problems.** A work in progress is the use of the results achieved in [22, 28] for stabilizing the approximation of discontinuous solutions of scalar conservation laws. These evolutionary partial differential equations can produce discontinuous solutions in finite time, also starting from smooth initial data. The classical finite element approximation will produce spurious oscillations generated around the discontinuities. Such oscillations then propagate all over the domain, making very poor the uniform approximation to the solution. The use of a Discontinuous Galerkin approximation also produces spurious oscillations, but it confines them just locally around the discontinuities. Still further stabilization methods are requested to get a good uniform approximation locally at the discontinuities. One way of addressing this problem is to add an additional viscosity (typically by minimizing the  $L^2$  norm of the gradient) out of the jumps of the solution. The information on the jump is typically obtained *explicitly* from the previous time-step, by assuming that it will not progress in time too quickly. Hence, one has to assume a rather small time step in order to keep stability of the entire scheme. However, we expect that a post-processing solution of a free-discontinuity problem, where the discontinuity set is *implicitly* computed at each time step, can furnish the same stabilization effect with respect to spurious oscillations, and at the same time it can allow for much larger time steps.
- (R3) **Further developments on adaptive methods for linear elliptic PDEs.** In the work [6, 8, 7, 9, 30, 31] we established a new approach to the adaptive solution of linear elliptic PDEs by means of redundant wavelet frame discretizations. While this technique allows for an easier use of wavelets on complex domains, it does not improve the best rate of approximation due to the fact that the

dictionary used for the discretization is a union of wavelet bases. By considering the union of “hybrid bases”, e.g., wavelets and local Fourier bases, we hope to obtain, at least for certain solutions, a rate of convergences (and a complexity) which is beyond the obtainable performance by using one basis only. The theory behind this development is closely related to compressed sensing and it is one very important example of how sparse optimization techniques can be employed in numerical simulation.

(R4) **Domain decomposition and subspace correction methods for nonsmooth convex minimizations.**

Domain decomposition and subspace correction methods are known to converge to solutions of PDEs associated to smooth strictly convex energies, and many counterexamples are known for nonsmooth and nonseparable cases. However, we succeeded to achieve the first proof of convergence of these methods [21] in the context of problems related to total variation minimization (known to be nonsmooth and nonseparable). This relevant result comes after several successful investigations [18, 27] in related topics. These achievements clarified the possible robust use of high-performance computing, in particular, parallel computing, for methods involving total variation minimization, see Figure 2. In the classical theory of domain decomposition methods for well-posed linear elliptic PDEs, such schemes turns out to be equivalent to optimal preconditioners for the problem, with a resulting condition number which scales as a constant with the mesh refinement. For degenerate elliptic PDEs (where coerciveness and boundedness may be lacking), this good scaling properties are not known, and we are currently investigating the right framework for establishing optimal choices of decomposition and estimates of the complexity growth with the mesh refinement.

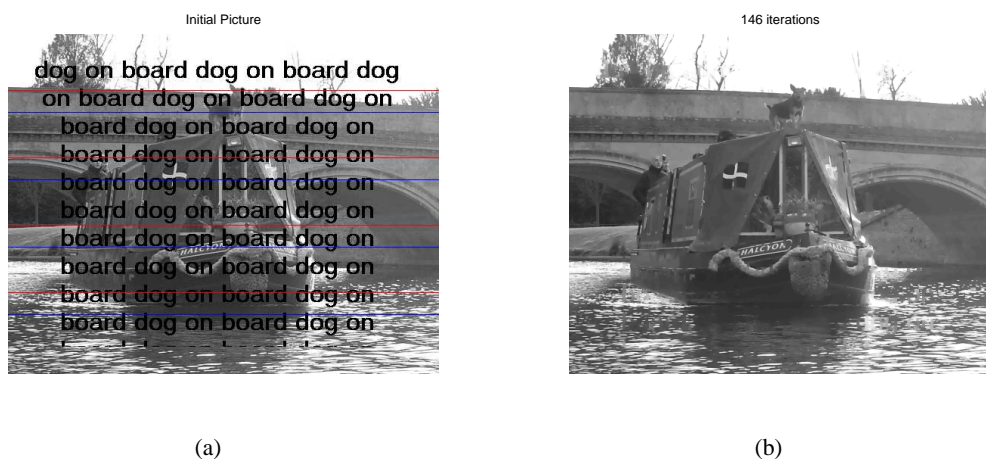


Figure 2: This figure shows an application of algorithm in [21] for image inpainting. In this simulation the problem was split into five subproblems on overlapping subdomains.

(R5) **Kinetic and hydrodynamic equations for collective behavior modeling.** Starting with individual-based models based on “particle”-like assumptions, we connect to hydrodynamic/macrosopic descriptions of collective motion via kinetic theory. We emphasize the role of the kinetic viewpoint in the modelling, in the derivation of continuum models and in the understanding of the complex behavior of multi-agent systems. In the recent studies [4, 5, 13] we clarified existence of solutions, stability, and pattern formation (e.g., as the one showed in Figure 3 related to fish schooling), of certain nonlinear PDEs associated to kinetic models, and we derived corresponding hydrodynamic equations [20]. This research direction is widely open with several questions to be yet clarified. Besides challenging theoretical issues, also the robust numerical analysis encounters the same difficulties as in the classical problems of fluid dynamics. Our wish is to address in a longer prospective problems where we do not dispose of given absolute interaction laws, such as the fundamental laws of physics ruling the particle behavior in diluted gas; instead we want to infer them mathematically via an inverse problem procedure from minimal observations, and then use such derived models for modelling hydrodynamic equations which might allow us to *forecast* unknown and fuzzy situations, for instance in biology or the behavior of large populations.

(R6) **High-dimensional dynamical systems.** The models studied, and mentioned above, for the motion behavior of animals and humans are typically embedded into the physical space. However, it is of very strong interest to consider a more abstract setting in high dimensions. For instance, we may want to consider a group of a few millions individuals, each characterized by a few thousand degrees of freedom, as it may be the case for a model of the financial market with several investors, characterized by relatively large portfolios. When the dynamics is ruled by the sole adjacency matrix of the cloud of agents (computed with respect to some distance), then the cost of simulating or learning the dynamical system becomes too large. In fact, at each time-step one should compute again the adjacency matrix with a cost of  $O(N \times N \times d)$  operations where  $N = d^\alpha$ ,  $\alpha > 1$  is the number of agents and  $d$  the dimension of their degrees of freedom. By the Johnson Lindenstrauss lemma, it is well-known that random linear projections onto a space of lower dimension  $k \approx \log(d)$  can behave almost isometrically on a cloud of  $N$  points. Hence one can simulate or learn approximatively the dynamical system in lower dimension, if we consider one or more random projections of it. Such simulations can be addressed in parallel. We obtained already several very surprising results in this very visionary research direction and we expect many more to come.

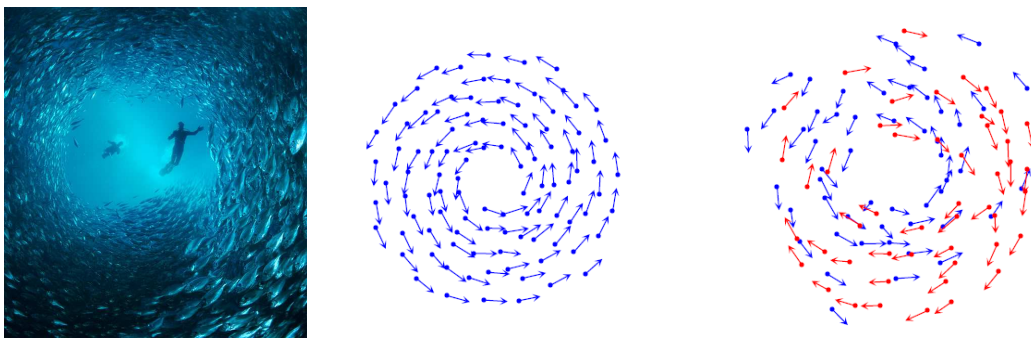


Figure 3: Mills in nature and in our numerical simulation.

Since July 2009, the group of “Analysis of Partial Differential Equations” acquired new members, Dr. Jan Haskovec, Dr. Karin Schnass, and Dr. Jan Vybiral, thanks to the funding obtained via the START-Pries project “Sparse Approximation and Optimization in High Dimensions”. This project is *highly interdisciplinary* and it has the function of connecting the activity of the group of “Analysis of Partial Differential Equations” to the research done within RICAM by other related groups, in particular, “Computational Mathematics for Direct Field Problems”, “Inverse Problems”, “Optimization and Control”, “Mathematical Imaging”, and “Mathematical Methods in Molecular and Systems Biology”. For more info <http://hdsparse.ricam.oeaw.ac.at/>.

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