Johann Radon Institute for Computational and Applied Mathematics

Österreichische Akademie der Wissenschaften

Doctoral and Postdoctoral positions up to 6 years at the Johann Radon Institute for Computational and Applied Mathematics – Linz – AUSTRIA within the

FWF-START project "Sparse Approximation and Optimization in High-Dimensions"

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Dear Colleague,

I would like to advertise an **opening from January 2009** of 2 Doctoral and 2 Postdoctoral positions for a period of maximal 6 years at the Johann Radon Institute for Computational and Applied Mathematics – Linz – AUSTRIA, within the FWF-START project "Sparse Approximation and Optimization in High-Dimensions". **The positions can start from April 1, 2009.**

Main research directions. The project will address an interdisciplinary research in the following directions:

- Calculus of variations: free-discontinuity inverse problems, in particular existence of solutions, identifiability of jumps from incomplete linear and nonlinear measurements, Gamma-convergence techniques, discrete approximations of continuous variational models, numerical methods;
- Sparse and combinatorial optimization: numerical methods for solving sparse optimizations with linear and nonlinear constraints, including iterative thresholding algorithms, subspace correction methods, projected gradient methods, nonconvex optimization;
- Numerical solvers for PDEs based on redundant decompositions**:** redundant hybrid decompositions (e.g., wavelets + local Fourier bases) are used to discretize PDEs, efficient adaptive computation of the sparsest solution representation;
- Operator compression**:** sparse approximation of full matrices by means of dictionaries of low-rank matrices;
- Learning theory: methods for reconstructing "low-rank" tensors from incomplete linear measurements, for instance, efficient exact reconstruction of low-rank matrices from few samples of the entries.

The tools developed within the project may be employed for real-life applications, for instance:

- Digital signal and image processing: digital signal and image coding and decoding, restoration from incomplete measurements, compressive sensing;

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- Inverse problems in medical diagnostics: magnetic tomography: magnetoencephalography (MEG) and multimodal brain imaging;
- Global terrestrial seismic tomography: combination of the finite-frequency theory, wavelet decompositions, and sparse optimization for recovery of the global structure of the Earth from seismic data;
- Marketing surveys: low-rank tensor completion will be used for guessing the appreciation of unrated products by customers in marketing surveys;
- Restoration of paintings from invisible light data: invisible light spectra provide fundamental additional information which can be used for the full re-colorization of deteriorated art paintings.

Invitation for applications. Brilliant candidates with a strong background in one or more of the following fields

functional analysis, calculus of variation and geometric measure theory, applied harmonic analysis (Fourier and wavelet methods), optimization and optimal control, numerical methods,

are invited for applications. We would like to offer:

- **Doctoral studies from a minimum of 3 to a maximum of 6 years**: the basic income after taxes is 1200 euro/month for 14 months, possibly negotiable according to the results; the brutto income includes social security (pension), health care coverage, and unemployment doll; each doctoral student will be provided with a personal laptop or a workstation, office space, and c.a. 3000 euro/year for research purposes (school attendance, conference participation, research visits abroad) to be managed independently.
  Requirements: master degree in applied mathematics (with topics in one or more of the fields indicated above) with best grades (summa cum laude).

- **Postdoctoral research (research scientist position) from a minimum of 1 to a maximum of 6 years:** the basic income after taxes is 1700 euro/month for 14 months, negotiable according to the initial qualifications, and during the project, according to the results; the brutto income includes social security (pension), health care coverage, and unemployment doll; each postdoctoral researcher will be provided with a personal laptop or a workstation, office space, and c.a. 5000 euro/year for research purposes (conference participation, research visits abroad) to be managed independently. Additionally the institute will be able to provide further financial support for exceptional motivations.
  Requirements: doctoral degree in applied mathematics with best grades, when such grades are given, in one of the best schools of the provenance country. It will be appreciated whether the candidate will present at least 1 single name publication (also a conference publication), denoting independent and inquiring attitude.

Applications. Your application will consist of:

- A concise application letter (1 page at most) describing yourself, research interests, and motivations for joining the project;
- Curriculum Vitae.
  Candidates for doctoral studies, please, emphasize the grades of your courses, and your final Master grade.
  Candidates for postdoctoral positions, please, emphasize school and the grades of the doctoral studies (if already concluded), and possible publication record;
- Letters of References.
  Candidates for doctoral studies, please, provide a letter of references of your Master thesis supervisor;
  Candidates for postdoctoral positions, please, provide 3 names and addresses of referees who will be willing to write reference letters.

Applications are submitted by email with title "Application for a START position" **at any time** from January 2009 to

massimo.fornasier@oeaw.ac.at

Yours sincerely

Massimo Fornasier

Further information about the project . "*START Prize 2008 - Sparse Approximation and Optimization in High Dimensions.*
The dimension scale of problems arising in our modern information society became very large. A new area of science and engineering is now urgently needed in order to extract and interpret significant information from the universe of data collected from a variety of modern sources (Internet, physics experiments, medical diagnostics, etc.). Numerical simulations at the required scale will be one of the great challenges of the 21st century. In short, we need to become capable of organizing and understanding complexity. The most notable recent advances in data analysis and numerical simulation are based on the observation that in several situations, even for very complex phenomena, only a few governing components are required to describe the whole dynamics; a dimensionality reduction can be achieved by demanding that the solution be "sparse" or "compressible". Since the relevant degrees of freedom are not prescribed, and may depend on the particular solution, we need efficient optimization methods for solving the hard combinatorial problem of identifying them. In this project we will first address the problem of designing efficient algorithms which allow us to achieve sparse optimization in high-dimensions. Secondly, the tools which we will develop for achieving adaptive dimensionality reductions will subsequently be used as building blocks for solving large-scale partial differential equations or variational problems arising in various contexts. Finally, we will apply the whole machinery to interesting applications in image processing, free-discontinuity and -boundary

problems, such as corrosion detection and crack identification, and we will explore new applications in innovative fields such as automatic learning. To do all of this, we will have to face several profound mathematical problems, such as the determination of well-conditioned column splitting of general matrices (called paving), the difficult estimation of the complexity of the algorithms we propose, and establishing their ability to compute the nearly-sparsest solution of the problem at hand. Tools from several different mathematical branches are needed. The relevant mathematics will include methods from applied harmonic analysis, functional analysis, probability theory, convex optimization, and calculus of variations. The main numerical techniques will include iterative thresholding algorithms, operator compression, random alternating projections, subspace correction, and domain decomposition methods."

Innovations

The currently known algorithms used for sparse optimization do not scale well with dimension. When the latter is large, these algorithms often turn out to be impracticable. Our project will investigate methods for dimension reduction which will allow us to solve efficiently sparse optimization problems in high-dimensions. Furthermore, most of the applications of sparse-recovery methods are currently addressed to the relevant problem of encoding and exactly decoding digital signals in a very economic way. In our project we would like to step beyond this particular class of problems. For instance, we will use our methods for global terrestrial seismic tomography, restoration of visual art operas from invisible light spectra, completion of marketing surveys for promoting unrated products to customers.

Our research institute and international cooperations. The Austrian Academy of Sciences (Oesterreichische Akademie der Wissenschaften, OEAW) is the leading organization promoting non-university academic research institutions in Austria.
The Johann Radon Institute for Computational and Applied Mathematics (RICAM) is one of the excellence research centers of OEAW. It is located in the campus of the Johannes Kepler University in Linz (Austria), it shares with it part of its infrastructure. Created on January 2003, RICAM currently consists of 7 working groups: Computational Mathematics for Direct Field Problems (Prof. Ulrich Langer), Inverse Problems (Prof. Heinz W. Engl), Symbolic Computation (Prof. Josef Schicho), Financial Mathematics (Dr. Peter Friz, Prof. Walter Schachermayer), Analysis of Partial Differential Equations (Dr. Massimo Fornasier, Prof. Peter Markowich), Optimization and Optimal Control (Prof. Karl Kunisch), Mathematical Imaging (Prof. Otmar Scherzer). As a mission statement, the Institute does basic research in computational and applied mathematics according to highest international standards. Due to its tight relationship with the Linz University, RICAM cooperates also by involving PhD-students into its research. Altogether RICAM has more than 730 square meters of office space. Moreover, since RICAM is embedded into the University Campus and shares the same infrastructure with the University, RICAM members can access all relevant facilities (network, library, mensa etc.).

The genuinely interdisciplinary environment, with a large number of ongoing research projects in applied and computational mathematics (http://www.ricam.oeaw.ac.at/projects/), and the continue interaction with the truly outstanding senior researchers which form the leaderships of RICAM offer a unique possibility for doctoral and postdoctoral researchers.

From an international point of view, our group has solid and long-standing active cooperations with several European research scientists, e.g., with the research groups of Stephan Dahlke (Marburg, Germany), Riccardo March (Rome, Italy), Peter Markowich (Cambridge, UK), Holger Rauhut (Bonn, Germany), Rob Stevenson (Amsterdam, Netherlands), Jared Tanner (Edinburgh, UK), Gerd Teschke (Berlin, Germany), on the themes of the project. Moreover, very solid and fruitful cooperations have been established since 2006 with Ingrid Daubechies (Princeton, U.S.A.), Ronald DeVore (Texas A&M, U.S.A.), Sinan Güntürk (Courant Institute NY, U.S.A.); we expect that such cooperations will contribute to the project, both with exchange of students and mutual research visits.