2012-2013 Annual Report

# PIMS CRG in Applied and Computational Harmonic Analysis

Here is a short summary of all CRG activities:

**1. Second Joint Alberta-BC seminar, August 26-30, 2013 at University of Calgary.**

**2. PIMS BIRS 2-day workshop, August 30-September 1, 2013 at Banff.**

**3. CRG PDFs and graduate students**

**4. List of PIMS visitors in 2013.**

**5. Collaborations and research activities of CRG members and their students, PDFs.**

**6. Some publications in 2013**.

## 1. Major Event of CRG in 2013: CRG Conference on Applied Harmonic Analysis (i.e., the Second Joint Alberta-BC Seminar), August 26-30, 2013 at University of Calgary.

The main objectives of the conference are

1) to report progress following the two academic years of CRG operation (for CRG faculty members, graduate students and postdoctoral fellows);

2) training graduate students and PDFs associated with CRG;

3) to discuss and state achievable goals for the last year of CRG funding;

4) bringing results and share ideas with broader mathematical community in the area.

All CRG members and their students/PDFs had an opportunity to present the results of their research. More than 50% of conference participants were PDFs, graduate or undergraduate students.The conference provided valuable experience to the junior participants and exposed them to cutting edge research directions in the field. Some directions for future research were discussed. In spite of the small size of the conference, there were participants from 4 countries, both Europe and Asia. There was also significant interest to the conference at the University of Calgary.

Organizers: Elena Braverman (University of Calgary), Bin Han (University of Alberta)

Participants:

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|---|---|---|---|
| Mohammed Aiffa, | Enrico Au-Yeung* (PDF) | Elena Braverman | Almaz Butaev (Student) |
| Yi Chang (Student) | Jian Deng* (PDF) | Tom Duchamp* | Hartmut Fuhr* |
| Navid Ghadermarzi* (Student) | | Md. Kamrujjaman (student) | |
| Bin Han* | Rong-Qing Jia* | Chun-Kit Lai* (PDF) | Peter Lancaster, |
| Wenyuan Liao | Michael Lamoureux* | Joshua MacArthur* (Student) | |
| Kateryna Melnykova (Student) | | Yi Shen* (PDF) | Qiyu Sun* |
| Kris Vasudevan | Kun Wang* (PDF) | Kunrui Wang (student) | Thomas Yu* |
| Yile Zhang (student) | Zhenpeng Zhao*(student) | Xiaosheng Zhuang* | Vladimir Zubov (PDF) |

**Note:** * indicates speakers in the joint Alberta-BC seminar.

**2. Event of CRG in 2013: PIMS BIRS 2-day workshop on recent progress on applied and computational harmonic analysis, August 30-September 1, 2013 at Banff.**

This 2-day workshop held 4 talks and formed a discussion session on recent advances on applied and computational harmonic analysis.

Speakers: Chun-Kit Lai, Joshua MacArthur, Ozgur Yilmaz, Thomas Yu.

Participants: Enrico Au-Yeung, Elena Braverman, Almaz Butaev, Tom Duchamp, Navid Ghadermarzi, Bin Han, Chun-Kit Lai, Joshua MacArthur, Kateryna Melnykova, Yi Shen, Qiyu Sun, Ozgur Yilmaz, Thomas Yu, Zhenpeng Zhao.

**3. CRG PDFs and graduate students**

**PIMS PDFs:**

1. Dr. Enrico Au-Yeung has been a PIMS PDF Aug 2011-2013 at the University of British Columbia, hosted by Ozgur Yilmaz. His research during over the last year has primarily focused on compressed sensing. In a project joint with O. Yilmaz, Enrico constructed a new class of random matrices and proved that these can be used as compressed sensing measurement matrices. The proof is based on the theory of non-asymptotic random matrix theory and geometry of Banach spaces. In another project that is joint with O. Yilmaz, H. Mansour and R. Saab, Enrico continued his work on compressed sensing via "jittered sampling". Enrico also worked on certain problems in frame theory. In one of these problems, he devised a procedure to convert a frame which is not a tight frame into a Parseval frame for the same space, with the requirement that each element in the resulting Parseval frame can be explicitly written as a linear combination of the elements in the original frame. See below for a list of Enrico's publications.

1) E. Au-Yeung, Signal recovery and frames that are robust to erasure. Submitted.

2) E. Au-Yeung and S. Datta, Tight frames, partial isometries, and signal reconstruction. Submitted.

3) E. Au-Yeung and S. Datta, Tight frames in spiral sampling, Proceedings of the International Conference on Sampling Theory and Applications (SampTA) 2013.

4) E. Au-Yeung and J.J. Benedetto, Balayage and short time Fourier transform frames, Proceedings of the International Conference on Sampling Theory and Appl. (SampTA) 2013.

2. Dr. Yi Shen is jointly hosted by Elena Braverman at University of Calgary and by Bin Han at University of Alberta. Data sets collected by image sensor are often corrupted by noise. Image denoising is a fundamental problem in the field of image processing. One class of methods which take the advantage of similar patches in images has been showed to be powerful approaches for image denoising. The basic idea of the patch-based method is collecting the similar patches as a group. Each group can be handled with some powerful methods such as weighted average, wavelets transform, wiener filter, higher order singular value decomposition and so on. Finally, the denoised image is reconstructed from all the groups. Motivated by the idea of block matching, we stack similar patches to be 3D or 4D groups in our proposed denoising algorithm. We name it as block matching and low rank

tensor approximation image denoising (BMTA) method. Mathematically, the group is named as tensor which is the high order generalization of vectors and matrices. Since the patches are similar, the tensor have near low rank properties. Then the higher order singular value decomposition techniques can be used to separate the real data and the Gaussian noise. The progress is supported by the low rank matrix approximation theory. The main feature in our algorithm is that we stack the similar patch as a tensor not a matrix, then we use an iterative algorithm to find an approximation for each given group. Compared with the BM3D which is regarded as the state-of-the-art image denoising method, the BMTA have higher PSNR value and more comfortable visual quality. Now we plan to consider the image inpainting problem. Especially, we are interested in the random sample case. In application, the image are assumed to be sparse in transform domain. Then the  minimization problem can be formed to find a good approximation of the real image. In the future, we would like to discuss the following questions: How to design a powerful transform and thresholding method to recover the image?

3. Dr. Kun Wang, at the University of Alberta, jointly hosted by Yau Shu Wong and Rong-Qing Jia. Dr. Wang has been progressing well. One paper already appeared in the Journal of Computational Physics, and one was resubmitted to the Communications in Computational Physics after a positive review.

1) Error correction method for Navier-Stokes equations at high Reynolds numbers in Journal of Computational Physics, Vol. 255, p.245-265, 2013

The Navier-Stokes equations have been used to model many important problems in engineering and physical sciences. The paper focuses on the error due to solving the nonlinear system. By solving and incorporating the estimated error terms, we improve the computed solutions. We prove that the convergent rate of the new scheme will produce at least three times faster compared to the Oseen scheme without the error correction. Numerical simulations were carried out for the test problems based on the one- and two-sided driven cavity problems. Not only do the new method lead to more rapid convergence rates; for a given mesh, it is also capable of solving the Navier-Stokes equations at higher Reynolds numbers than the original Oseen scheme without the error correction step. Compared with the original Oseen scheme, an impressive CPU time saving of up to 82% is achieved by the use of the new method for cases with high Reynolds numbers.

2) Pollution-free finite difference schemes for non-homogeneous Helmholtz equation, resubmitted to the Communications in Computational Physics

The Helmholtz equation arises from time-harmonic wave propagation, and the solutions are frequently required in many applications such as aero-acoustic, electromagnetic wave scattering, geophysical problems, etc. This paper presents a novel approach to develop high-order finite difference schemes. The scheme is optimal among currently available numerical algorithms for the Helmholtz equation. It is demonstrated for a homogenous media, exact solution can be obtained at any wave number and with no restriction on the step size h. The paper focuses on the derivation and convergent analysis for one-dimensional problem, and numerical simulations were reported for cases with constant and varying wave numbers. The work has been successfully extended to multi-dimensional problems, and the results will be submitted for journal publication.

### Graduate students and other PDFs in 2013 at UA:

1. Menglu Che, MSc student, co-supervised by Y. S. Wong and B. Han, graduated in July 2013.

2. Jian Deng, PhD student, supervised by Yau Shu Wang. Graduated in April 2013. Participated in the second joint Alberta-BC seminar and presented a talk on his work, currently working on numerical analysis. Now work at University of Alberta as a MITACS PDF.

3. Li Zhang, PhD student, co-supervised by Peter Minev and Bin Han.

4. Yile Zhang, PhD student, supervised by Yau Shu Wong. Completed first qualifying year at UofA, and started research.

5. Zhenpeng Zhao, PhD student, supervised by Bin Han. Participated in second joint Alberta-BC seminar and presented a talk on his work. Also participated in PIMS-BIRS 2-day workshop on recent progresses on applied harmonic analysis. Currently working on applications of directional framelets in image processing.

6. Mpafareleni R. Gahvi, NRF PDF, hosted by Bin Han, fully supported by National Research Foundation in South Africa. Completed her PDF and now working as a PDF in South Africa.

7. J. Keating, PhD student, co-supervisored by Peter Minev, working on direction-Splitting Schemes For Particulate Flows.

8. A. Roshchenko, PhD student, co-supervisored by Peter Minev, working on numerical studies of fiber deposition in human airways.

9. M. Khageh, PhD student, supervisored Peter Minev, working on parallel algorithms for nonisothermal oil reservoirs.

10. S. Alami, MSc student, co-supervisored by Peter Minev, working on investigation of algorithms for solving electro-cardiac activity.

11. V. Zingan, PDF, co-supervisored by Peter Minev, working on development of an open source fuel cell framework.

### Graduate students in 2012 and other PDFs at UBC:

1. Arman Ahmadieh, PhD student, supervised by Ozgur Yilmaz, working on several problems

regarding deterministic measurement matrix construction in compressed sensing and quantization of measurements obtained using deterministic constructions.

2. Kateryna Melnykova, PhD student, supervised by Ozgur Yilmaz, working on understanding the approximation accuracy associated with the so-called memoryless scalar quantization in the setting of random frames.

3. Navid Ghadermarzy, PhD student, supervied by Ozgur Yilmaz, joined the PhD program in September 2013, working on various mathematical problems motivated by seismic signal processing.

4. Oscar Lopez, PhD student, co-supervied by Ozgur Yilmaz and Felix Herrmann (UBC Earth, Ocean, and Atmospheric Sciences), joined the PhD program in September 2013, taking courses.

5. Brock Hargreaves, MSc student, supervied by Ozgur Yilmaz, working on alternative sparse recovery formulations in compressed sensing, specifically when the sparsifying dictionary is a redundant frame.

6. Xiaowei Li, MSc student, supervied by Ozgur Yilmaz, started program in September 2013, taking courses.

7. Rongrong Wang, PDF, co-supervised by Ozgur Yilmaz and Felix Herrmann, has joined us in September 2013 after receiving her PhD in University of Maryland, College Park, working under the umbrella of the project DNOISE2, which is a collaborative project between Ozgur Yilmaz (Math), Felix Herrmann (EOAS), and Michael Friedlander (CS) funded by the industry and NSERC.

**Graduate students in 2012 at UV:**

1. Seyedali Mostafavian, PhD student, supervised by Michael Adams, working on triangle mesh models of images based on constrained Delaunay triangulations.

2. Xiao Ma, MASc student, supervised by Michael Adams, working on triangle mesh models based on data-dependent triangulations for image representation.

3. Xiao Feng, MASc student, supervised by Michael Adams, working on coding/compression of mesh models based on data-dependent triangulations for image compression.

4. Badr Eddine El Marzouki, MASc student, supervised by Michael Adams, taking courses.

Note: currently on 8-month Coop internship with Broadcom.

5. Dan Han, MASc student, supervised by Michael Adams, taking courses.
Note: currently on 8-month Coop internship with Broadcom.

6. Xiaoxi Du, MASc student, supervised by Michael Adams, taking courses.
Note: currently on 8-month Coop internship with Broadcom.

7. Yue Fang, MASc student, supervised by Michael Adams, taking courses.

8. Feng Zhu, MASc student, supervised by Michael Adams, taking courses.

9. Yue Tang, MEng student, supervised by Michael Adams, taking courses.

**4. PIMS Visitors:**

1. Xiaosheng Zhuang (City University of Hong Kong), August 15-30, 2013, hosted by Bin Han at UA, participated in the second Joint Alberta-British Columbia Seminar.

2. Alexandra Rodkina (University of West Indies), July 2013, hosted by Elena Braverman at UC.

3. J.L. Guermond (Texas A&M University), August 2013, hosted by Peter Minev at UA.

4. B. Sendov (Institute of Mathematics, Bulgarian Academy of Sciences), February 2013, hosted by Peter Minev at UA, presented a PIMS-AMI seminar talk.

**5. Collaborations and Research Progresses of CRG members, their students & PDFs:**

**Michael Adams at the University of Victoria:**

Michael Adams at the University of Victoria: My research group has been continuing its work on triangle mesh representations of images. This work has involved: 1) developing new mesh models for images; 2) devising effective methods for the selection of the parameters for these models for a given image (i.e., the mesh-generation problem); and 3) techniques for efficiently encoding these models (i.e., the data compression problem). Ali Mostafavian has started his research project this year and has been building on the work of Xi Tu, a past student in the group. Xi had proposed a mesh-generation method for image representation that utilizes constrained Delaunay triangulations. He is currently investigating several possible avenues for improving Xi's method based on the results of his analysis. Brian Ma finished a one-year Coop internship in August 2013. He is currently conducting a detailed literature review of mesh approximation methods that employ data-dependent triangulations, with a primary focus on mesh-generation methods. Joyce Feng finished an 8-month Coop internship in April 2013. Since then, she has been focused on learning more about the C++ programming language and the CGAL library which will be needed in her research project. Currently, Joyce is working on developing a image compression method that utilizes representations of images based on data-dependent triangulations. Michael Adams developed a new image coding method based on Delaunay meshes that support progressive lossy-to-lossy functionality and has vastly superior coding efficiency relative to other competing schemes. This method is presented in his 2013 IEEE PACRIM conference. Over the past decade, Michael Adams has been involved with numerous research projects with his graduate students that relate to wavelets. In order to assist in the training of his graduate students in this area, Michael developed a textbook on multiresolution signal and geometry processing. After undergoing many changes over the last several years, Michael has published the textbook this year using a Creative-Commons (i.e., open-access) license so that other faculty and students may also benefit from it (at no cost). Additional information about the textbook as well as a PDF of the textbook for download can be obtained from the following web page: http://www.ece.uvic.ca/~mdadams/waveletbook

**Elena Braverman at the University of Calgary:**

In July 2013, I had a research visitor Alexandra Rodkina (the University of West Indies, Jamaica) with whom we explore the influence of stochastic perturbations on the behaviour and the spectrum of various models. So far we proved that in the case of an asymptotically decaying noise the results coincide with non-stochastic case (this result was published in 2013 in the Journal of Difference Equations). The situation when the noise is bounded is more complicated, and depends on the noise bounds. This project was advanced during A. Rodkina's visit to Calgary, a paper was submitted for publication. During the past year my PhD student Lyudmila Korobenko, together with my colleague and her co-supervisor Cristian Rios obtained some important results in the area of elliptic PDE's. She investigated regularity of second order infinitely degenerate elliptic operators as well as the properties of associated metric spaces. One of the ways to describe the regularity of weak solutions is in terms of the operator being subelliptic or hypoelliptic. The criteria of subellipticity for linear operators have been given by Hormander (1967) in terms of vector fields associated to the operator; and by Fefferman and Phong (1981) in terms of subunit metric balls associated to the operator. In particular, it follows that an infinitely degenerate operator cannot be subelliptic. For the infinitely degenerate quasilinear operators hypoellipticity has been recently shown by Rios et al (2011) in the assumption that the coefficients can only vanish on hyperplanes. This result, however, relies on the a priori assumption that the solution is continuous. We showed that every weak solution to a certain class of degenerate quasilinear equations of divergence form is continuous, thus completing the result on hypoellipticity.

**Tom Duchamp at University of Washington:**

A linear subdivision scheme is a procedure for constructing curves in as the limit of a sequence of subdivisions of a polygon followed by an averaging procedure. The first such scheme was given by Georges de Rham in the early 1950's. The resulting curves, called subdivision curves, have a so-called multi-resolution structure and are closely related to wavelets. Subdivision curves and subdivision surfaces (their bi-variate generalization) have become a standard tool in many fields, including statistics, approximation theory, and computer aided geometric design, and there is a well-developed regularity and approximation theory for them. In 2001, motivated by the explosion of manifold-valued data, Donoho presented a construction of a nonlinear subdivision scheme which served as the basis of a nonlinear wavelet transform for the muli-scale representation of such data. Each such nonlinear scheme is based on a linear subdivision scheme, and a fundamental question is to determine necessary and sufficient conditions for the regularity properties of the linear scheme to be inherited by the corresponding nonlinear scheme---this is the so-called smoothness equivalence problem, and the focus of my research under the CRG. Various sufficient conditions for smoothness equivalence, called "proximity conditions" have been known for some time. We analyzed these conditions for an important class of nonlinear subdivision schemes called the single-base point log-exp schemes, and showed that -equivalence breaks down on manifolds with non-vanishing curvature. And we solve succeeded the smoothness equivalence problem in general. Our solution involves ideas and methods from differential geometry, dynamical systems, and analysis. We presented our most recent work at the conference in Calgary.

**CRG members at the University of Alberta:**

In the past year, Rong-Qing Jia investigated fast numerical computation based on multilevel approximation. He collaborated with Qianshun Chang of Chinese Academy of Sciences on multigrid methods. They completed a joint paper entitled “A Refined Convergence Analysis of Multigrid Algorithms for Elliptic Equations”, which was accepted for publication in Analysis and Applications. In this paper, they established a very general theory for convergence of multigrid algorithms. The convergence analysis established in their paper does not require any additional regularity of the solution and is valid for more general smoothers including the Gauss-Seidel method. As a result, the general theory of multigrid algorithms developed in this paper has a wider range of applications to problems arising from science and technology. Rong-Qing Jia himself also completed a paper entitled“Applications of Multigrid Algorithms to Finite Difference Schemes for Elliptic Equations with Variable Coefficients, which was accepted for publication in SIAM Scientific Computing. For finite difference schemes applied to elliptic equations with variable coefficients, the convergence rate of the multigrid algorithms given in the existent literature depends on the number of levels. His paper established a convergence rate independent of the number of levels. Moreover, details of implementation of the multigrid algorithms and numerical examples were given in the paper.

Together with Rong-Qing Jia, Yau Shu Wong provided financial support for Kun Wang, a PIMS

PDF. They made joint investigation on numerical solutions of partial differential equations. The research collaborations between Yau Shu Wong and his PIMS PDF have already been described in the category of PIMS PDFs. Yau Shu Wong currently supervises a MITACS PDF, Jian Deng, who completed his PhD program in summer 2013. They study the symplectic schemes for stochastic Hamiltonian systems (SHS). The symplectic integration is a special type of numerical method capable of preserving the symplecticity properties of the Hamiltonian system, and the accuracy of the computed solution by using this method is guaranteed for long term computation. Following the work of Milstein et al. They study the symplectic schemes for SHS. Using the properties of multiple stochastic integrals, a recursive formula to determine the coefficients of the generating function is derived. Theoretically, this formula allows us to construct stochastic symplectic stochastic schemes of arbitrary high order. They also prove that the coefficients of the generating function are invariant under permutations for SHS preserving Hamiltonian functions. The importance of the result is that the construction of the strong and weak symplectic schemes of order two and three will be simpler and more efficient than the non-symplectic explicit Taylor expansion schemes with the same order. Numerical simulations clearly demonstrated this conclusion.

Bin Han and his group have currently been working on the construction of compactly supported tight framelets with good directional selectivity and the applications on image processing. Bin Han and Zhenpeng Zhao have been working on understanding dual-tree complex wavelet transform by ways of tight framelets. This not only provides a deeper theory for dual-tree complex wavelet, but also provide the way to improve the performance in image denoising. We expect that the results will be summarized in a forthcoming paper soon. Visitor Qun Mo, Zhenpeng Zhao, and Bin Han have been working on several interesting problems on constructing one-dimensional tight wavelet frames, which are of particular interest for their applications in image denoising. We provide both a metric to measure the frequency separation and an algorithm to construct compactly supported directional tight framelets. During Xiaosheng Zhuang's visit, Xiaosheng Zhuang, Bin Han, and Zhenpeng Zhao have developed a software to implement the tensor product tight framelet with applications in image denoising. We are currently working on the thresholding strategy to push the denoising performance with tensor product tight framelets.

Peter Minev has worked with J.L. Guermond, Texas A&M University, for many years together on the development and analysis of various algorithms for problems related to incompressible flow and magnetohydrodynamics, and with M. Secanell, Mech. Eng., University of Alberta, on the development of an open source framework for simulation of PEM fuel cells. His current activities are focused on the following projects:

1. Development of efficient parallel schemes for extremely-large scale simulations of incompressible and variable density flows.
2. Fluid-structure interaction flows in biomechanics.
3. Models for PEM fuel cells.
4. Parallel algorithms for heavy oil reservoirs.

**Bernie Shizgal at the University of British Columbia:**

The travel funds made available were used to fund the visit, July 8-13, 2013, of Dr. Livio Gibelli, Dipartimento Di Scienze E Tecnologie Aerospaziali, Politecnico di Milano, Milan, Italy. Dr. Gibelli had previously proofread portions of the book written by Dr. Shizgal on Spectral Methods in Chemical Physics to be published by Springer. The meeting in Vancouver in July provided additional valuable feedback on many aspects of Fourier analysis, spectral methods as well as wavelets discussed in the book. Dr. Gibelli has employed the half-range Hermite polynomials in the paper entitled "Velocity slip coefficients based on the hard-sphere Boltzmann equation", Phys. Fluids 24, 022001 (2012) that employed the half-range Hermite polynomials which are also referred to as the Maxwell polynomials developed by Dr. Shizgal. Additional applications of these basis sets to other rarefied gas dynamical problems is ongoing. Of particular importance were the discussions concerning the use of Fourier methods. The details of the applications of these Fourier methods to the nonlinear Boltzmann equation were clarified. Comparisons of these Fourier methods with other types of spectral methods and also with regard to quantum mechanical problems in Chemical Physics is ongoing.

**Ozgur Yilmaz at University of British Columbia:**

Currently, Ozgur Yilmaz and his group have been working on two main areas.

1. Quantization for frame expansions and compressed sensing: The compressed sensing literature has successfully established that this paradigm is effective for dimension reduction. However, with the existing "quantization" (i.e., replacing the measurement values with finite bit-streams) techniques, one needs to spend significantly more bits per measurement, rendering compressed sensing inefficient for compression. Therefore, obtaining good quantization methods is an extremely important problem that is underaddressed until recently. In a series of projects, we have shown over the last few years that sigma-delta quantization provides an effective alternative for compressed sensing quantization. These results, joint with several people including Rayan Saab (former student and CRG visitor) and Sinan Gunturk (CRG visitor) were published, for example, in Foundations of Computational Mathematics in 2013. Currently, Yilmaz is continuing to work in this rich field together with his PhD students A. Ahmadieh and K. Melnykova, as well as the new PDF R. Wang.
2. Compressed sensing and applications to seismic signal processing: The problems in this category fall under the umbrella of the project DNOISE2. This is an interdisciplinary research group that aims to use cutting-edge mathematical and computational techniques, such as compressed sensing and computational optimization, to drive innovation in exploration seismology. This group is run by three PIs: Ozgur Yilmaz (Mathematics), Felix Herrmann (Earth, Ocean, and Atmospheric Sciences), and Michael Friedlander (Computer Science). In addition, there are 5 post-doctoral fellows, 15 PhD students, and 5 MSc students that work on various problems within the scope of this project. Ozgur Yilmaz and his group's main contribution over the last year has been investigating how to incorporate prior information to the various sparse recovery methods that are computationally tractable. For example, with N. Ghadermarzy (MSc student at the time) and H. Mansour (former PDF), they proved that non-convex optimization is a viable alternative and can improve performance if there is some prior information on the signal to-be-reconstructed. This work will be submitted to a journal soon.

Alumni (where they are):

1. Rayan Saab (former PhD student of O. Yilmaz): After spending two years at Duke University as a Banting Postdoctoral Fellow, Rayan joined the Mathematics Department at UC San Diego as a tenure-track assistant professor.

2. Hassan Mansour (former PDF of O. Yilmaz and F. Herrmann): After spending three productive years with us, Hassan joined Mitsubishi Electric Research Laboratories (MERL), Boston, MA, USA as a permanent research staff.

## 6. Some publications in 2013:

### Michael Adams at the University of Victoria:

1. M. D. Adams, "Multiresolution Signal and Geometry Processing: Filter Banks, Wavelets, and Subdivision", University of Victoria Press, Victoria, BC, Canada, 2013, xxxviii + 538 pages.

2. X. Tu and M. D. Adams, "Improved Mesh Models of Images Through the Explicit Representation of Discontinuities," IEEE Canadian Journal of Electrical and Computer Engineering, vol. 36, no. 2, Spring 2013, pp. 78-86, DOI: 10.1109/CJECE.2013.6601083.

3. P. Li and M. D. Adams, "A Tuned Mesh-Generation Strategy for Image Representation using Data-Dependent Triangulation," IEEE Transactions on Image Processing, vol. 22, no. 5, May 2013, pp. 2004-2018, DOI: 10.1109/TIP.2013.2244217.

4. M. D. Adams, "A Flexible Incremental/Decremental Delaunay Mesh-Generation Framework for Image Representation," Signal Processing, vol. 93, no. 4, Apr. 2013, pp. 749-764, DOI: 10.1016/j.sigpro.2012.09.017.

5. M. D. Adams, "An Improved Progressive Lossy-to-Lossless Coding Method for Arbitrarily-Sampled Image Data," in Proc. of IEEE Pacific Rim Conference on Communications, Computers, and Signal Processing, Victoria, BC, Canada, Aug. 2013, to appear.

6. P. Li and M. D. Adams, "An Effective Mesh-Generation Strategy for Image Representation using Data-Dependent Triangulation," in Proc. of IEEE Pacific Rim Conference on Communications, Computers, and Signal Processing, Victoria, BC, Canada, Aug. 2013, to appear.

### Elena Braverman at the University of Calgary:

1. L. Berezansky and E. Braverman, Stability of equations with a distributed delay, monotone production and nonlinear mortality, Nonlinearity 26 (2013), 2833-2849.

2. E. Braverman, A. Rodkina, Stabilization of two cycles of difference equations with stochastic perturbations, J. Difference Equ. Appl. 19 (2013), 1192-1212.

3. L. Berezansky, E. Braverman and L. Idels, Mackey-Glass model of hematopoiesis with non-monotone feedback: Stability, oscillation and control, Appl. Math. Comput. 219 (2013), 6268-6283.

4. L. Korobenko, Md. Kamrujjaman and E. Braverman, Persistence and extinction in spatial models with a carrying capacity driven diffusion and harvesting, J. Math. Anal. Appl. 399 (2013), 352-368.

5. L. Berezansky, E. Braverman and L. Idels, Mackey-Glass model with monotone feedback revisited, Appl. Math. Comput. 219 (2013), 4892-4907.

6. L. Korobenko and C. Rios, Hypoellipticity of certain infinitely degenerate second order operators, J. Math. Anal. Appl. 409 (2014), 41-55.

**Tom Duchamp at the University of Washington:**

1. Tom Duchamp, Gang Xie, and Thomas Yu, Single basepoint subdivision schemes for manifold-valued data: time-symmetry without space-symmetry, Found. Comput. Math. (published online 29 Jan 2013).

2. Tom Duchamp, Gang Xie, and Thomas Yu, A new proximity conditions for manifold-valued subdivision schemes, (manuscript in preparation).

**Bin Han at the University of Alberta:**

1. Bin Han, Matrix splitting with symmetry and symmetric tight framelet filter banks with two high-pass filters, Applied and Computational Harmonic Analysis, Vol. 35 (2013), Issue 2, 200-227.

2. Bin Han, Properties of discrete framelet transforms, Mathematical Modelling of Natural Phenomena, Vol. 8 (2013), Issue 1, 18--47.

3. Bin Han and Xiaosheng Zhuang, Algorithms for matrix extension and orthogonal wavelet filter banks over algebraic number fields, Mathematics of Computation. Vol. 82 (2013), 459-490.

4. Bin Han and Zhenpeng Zhao, Image Denoising Using Tensor Product Complex Tight Framelets with Increasing Directionality, submitted.

5. Bin Han, Qun Mo, Zhenpeng Zhao: Compactly Supported Tensor Product Complex Tight Framelets with Directionality, submitted.

**Peter Minev at the University of Alberta:**

1. J. Keating, P. Minev, A Fast Algorithm for Direct Simulation of Particulate Flows Using Conforming Grids. Available online: J. Comp. Phys.

2. J.L. Guermond, P. Minev, Efficient parallel algorithms for unsteady incompressible flows. In: Iliev et al. (Eds), Numerical solution of PDEs: theory, algorithms, and their applications, Springer Proceedings in Mathematics & Statistics, 45 (2013).

3. T. Gornak, J.L. Guermond, O. Iliev, P.D. Minev, A direction splitting approach for incompressible Brinkman flow. In press in: Int. J. Numer. Analysis Modeling, part B.

4. R. C. Martinez, A. Roshchenko, P. Minev, W.H. Finlay, Simulation of enhanced deposition due to magnetic eld alignment of ellipsoidal particles in a lung bifurcation. J. Aerosol Medicine Pulmonary Drug Delivery, 25 (2012).

**Bernie Shizgal at the University of British Columbia:**

1. R. Sospedra-Alfonso and B. D. Shizgal, Energy and shape relaxation in binary atomic systems with realistic quantum cross sections, J. Chem. Phys. 139, 044113 (2013).

2. R. Sospedra-Alfonso and B. D. Shizgal, Hot atom populations in the terrestrial atmosphere. A comparison of the nonlinear and linearized Boltzmann equations, AIP Conf. Proc. 150, 91-98 (2012).

3. R. Sospedra-Alfonso and B. D. Shizgal, Henyey-Greenstein Model in the Shape Relaxation of Dilute Gas Mixtures, Transport Theory and Statistical Physics, 41, 368-388 (2012).

**Yau Shu Wong at the University of Alberta:**

1. K. Wang and Yau Shu Wong, Error correction method for Navier-Stokes equations at high Reynolds numbers, Journal of Computational Phys 255, 245-265 (2013).

2, K. Wang and Yau Shu Wong, Pollution-free finite difference schemes for non-homogeneous Helmholtz equation, submitted.

3. J. Deng and Yau Shu Wong, High-order symplectic schemes for stochastic Hamiltonian systems, submitted.

4. Symplectic schemes for stochastic Hamiltonian systems preserving Hamiltonian functions, accepted by International Journal of Numerical Analysis & Modeling, June 2013.

**Ozgur Yilmaz at the University of British Columbia:**

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