IMA 2000-2001 Annual Report

Supplementary Material

Postdoctoral Fellow Reports

IMA 2000-2001 Postdoc Report of Javier Armendariz

As a postdoc for the Institute for Mathematics and its Applications (IMA) annual program Reactive Flow and Transport Phenomena, I was exposed to multiple facets of the subject and given numerous opportunities to strengthen my scientific training. During the 2000-2001 program year I was involved with the Industrial program as well as pursued my own research interests.

Participating with the industrial program exposed me to the type of mathematical problems which interest the industrial community. I began work on a computational model of a Vertical Cavity Surface Emitting Laser (VCSEL) to be used by Honeywell which was proposed by Allen Cox of Honeywell Laboratories. In addition to this I was able to learn of the projects the other postdocs were involved in. This motivated me enough to pursue employment in industry as opposed to academia. From my personal research interests, I had a paper accepted for publication in the Journal of Fluid Mechanics [1] and was able to complete the writing for a second paper from my thesis [2], as well as take ample time for my job search. I continued my research by expanding some combustion models I had proposed in my thesis as well as work on problems I had begun the year previous. One of the more interesting of these is the effect of boundaries on the film evolution and combustion processes modeled in the paper to appear in JFM. In this problem, boundary layer solutions are needed to describe the model completely and the nature of the flame at its edges is no longer well understood and assumable. This second year of my postdoc has been extremely helpful in allowing me to continue work begun the year previous, during my regular program year, such as the pyrolysis and flow of a solid fuel. Work initiated from a conversation with Howard Baum.

My second year as a postdoc has proven to be a personally fruitful and productive opportunity for my scientific development. I have thoroughly enjoyed and gleaned much from the constant interaction with colleagues and visitors. I am grateful to the IMA and its staff for providing an environment conducive to scientific growth.

References

[1] Evaporation and Combustion of Thin Films of Liquid Fuels, J. Fluid Mech., 435 (2001) pp.351-376.

[2] Effects of nonsoluble surfactants at a liquid-vapor interface of a burning thin film, To be submitted.

IMA Postdoc Report for 200-2001 of Santiago I. Betelu

The main topics for my research during the last year have been Computer Vision and Fluid Mechanics. Below detail some of the results. These research projects are still under way.

Study of a method for denoising surfaces with shape texture I developed a simple method to denoise triangulated and implicit surfaces in a manner which preserves the 3D shape texture. The technique is based upon the synthesis of partial differential equations (PDE's), implicit surfaces, and Wiener filtering. The basic idea is to apply a computationally efficient local Wiener filter to an implicit representation of the surface. Such a representation can be directly given as the algorithm input or explicitly obtained via partial differential equation based implicitation techniques applied to the triangulated data. The proposed method has a computational complexity $O(N \log N)$ [4].

Affine Invariant Erosion of 3D Shapes I explored a new definition of affine invariant erosion of 3D surfaces, where instead of being defined in terms of euclidean distances, the volumes enclosed between the surface and its chords are used. The resulting erosion is thereby insensitive to the noise on the surface and it is affine invariant. I proved properties and proposed a simple method to compute the erosion of implicit surfaces1. I also discussed how the affine erosion may be used to define 3D affine invariant skeletons [1].

Capillarity driven spreading of power-law fluids In collaboration with Dr. M. Fontelos (IMA visitor from Universidad Rey Juan Carlos Mostoles) I investigated the spreading of thin liquid films of power-law rheology, which are relevant to coating processes and painting. We constructed an explicit travelling wave solution and source-type similarity solutions. We found that when the nonlinearity exponent λ for the rheology is larger than one, the governing dimensionless equation $h_t + (h^{\lambda+2}|h_{xxx}|^{\lambda-1}h_{xxx})_x = 0$ admits solutions with compact support and moving fronts. We also show that the solutions have bounded energy dissipation rate. This work has implications on thin film coating of surfaces with fluids at a scale of a milimeter or less. It is also of theoretical interest on PDE's as an interesting example of fourth order degenerate diffusion with compact suported solutions [3].

Focusing of non-circular self-similar shock waves In collaboration with Prof. D. Aronson (Mathematics department UMN) I studied the focusing of non-circular shock waves in a perfect gas. We constructed an explicit self-similar solution by combining three convergent plane waves with regular shock reflections between them. Then we showed with a numerical Riemann solver that there are initial conditions with smooth shocks whose intermediate asymptotic stage is described by the exact solution. Unlike focusing circular shocks, our self-similar shocks have bounded energy density [2].

Current work Currently I am doing research on evolution of surfaces driven by gaussian curvature. This flow has been used in Computer Graphics for the smoothing of noisy surfaces. The problem is also of great interest in Differential Geometry. Specifically I am studying the evolution of flat portions of the surface. These flat portions dissapear in a finite time as $area = (T-t)^{\alpha}$, where α is the *similarity exponent*, which is the solution of an eigenvalue problem. I am computing the similarity exponent α. Two methods are being used: a shooting method with an ODE describing a class of asymptotic solutions, and full numerical simulations of the problem. The goal is to compare both results and obtain good estimates of the exponent α.

Works written during my stay at IMA

1. Affine Invariant Erosion of 3D Shapes, S. Betelu, G. Sapiro, A. Tannenbaum, accepted at the ICCV'2001 conference in computer vision .
2. Focusing of non-circular self-similar shock waves, S. Betelu and D. Aronson, submitted to Physical Review Letters .
3. Capillarity driven spreading of power-law fluids, S. Betelu and M. Fontelos, submitted to Applied Mathematics Letters and IMA preprints .
4. A method for denoising surfaces with shape texture, S. Betelu, G. Sapiro, A. Tannenbaum, for the SIAM Conference on Imaging Science 2001 .
5. Noise Resistant area-based medial axis of planar curves, S. Betelu, G. Sapiro and A. Tannenbaum, submitted to Pattern Recognition .

Annual Report of Jamylle Carter

As a Postdoctoral Member of the Institute for Mathematics and its Applications (IMA Postdoc), my most significant accomplishment was the completion of my Ph.D. in Mathematics at the University of California, Los Angeles (UCLA). I came to the IMA in September 2000 with significant completed research but no finished thesis. I spent one week at UCLA in November 2000 in collaboration with my dissertation advisor Tony F. Chan. With the support and encouragement of the IMA staff and directors, I wrote my dissertation (Dual Methods in Total Variation-Based Image Restoration) in two months, and I defended and filed it in January 2001.

I also participated in the tutorials, workshops, and seminars held during the "Mathematics in Multimedia" program. During the Fall Quarter (Vision, Speech, and Language), I especially enjoyed the short course "Mathematical Methods in Speech and Image Analysis," which included outstanding lectures by Stu Geman and Guillermo Sapiro. I talked with both of them about potential connections with my research. The workshops "Mathematical Foundations of Speech Processing and Recognition" and "Mathematical Foundations of Natural Language Modeling" provided a great introduction to the fascinating fields of speech processing and natural language modeling. The IMA Career Workshop: Connecting Women in Mathematical Sciences to Industry led to a helpful conversation with fellow UCLA alumnus Karen Pao (Los Alamos National Laboratory) about strategies for completing my Ph.D. At the IMA Workshop 6B: Digital Libraries: Classification, Retrieval, and Visualization, I met Michael Smith (AVA Media), who also gave me tips for making the transition from graduate student to professional.

I presented my work at the IMA Postdoc Seminar in March 2001, and I gave an invited talk at the Mathematics Colloquium in the Department of Mathematics at North Dakota State University in April 2001. I was also an invited speaker for the 7th Conference for African American Researchers in the Mathematical Sciences at Duke University in June 2001.

The most interesting workshop topic was that of computer graphics. I have begun talking with Tom Duchamp (University of Washington), Rachel Kuske (University of Minnesota), and Victoria Interrante (University of Minnesota) about future career plans and strategies for making the most of my next year with the IMA.

IMA 2000-2001 Postdoc Report of Yalchin Efendiev

My research activities for this year are in the areas of upscaling methods for two-phase flow, modeling and computation of internal phase segregation during aerosol coagulation and investigating the self heating of bistable chains.

Besides my research, I have been teaching in Fall semester of 2000.

On the upscaling of two-phase flow we (with Lou Durlofsky, Department of Petroleum Engineering, Stanford University) have extended our previous work (published in ”Water Resources Research” Vol. 36, No. 8, pg. 2031-2041) on the upscaling of single phase flow. The new results are significant extension of the previous and includes the nonlinear effects. Currently, we are trying to incorporate additional physical effects into the model. Our work titled “Numerical Modeling of Subgrid Heterogeneity in Two Phase Flow Simulations” has been submitted to Water Resources Research.

The work on computation and modeling internal phase segregation during aerosol coagulation is in collaboration with Mitch Luskin (University of Minnesota), Henning Struchtrup (University of Victoria), Michael Zachariah (Univeristy of Minnesota). We have studied the sectional [2] where the internal state of the aerosol particles were described by basic statistics. In a separate work [3] with M. Zachariah we have proposed a simple model where we take the enclosure distribution to be monodisperse. The sectional models mentioned above have certain limitations and it is difficult to include additional physical effects into the framework. In our two subsequent papers [4,5] with Michael Zachariah we propose new Monte-Carlo approaches and study them.

The work on self heating of bi-stable chains is in collaboration with Lev Truskinovsky (Univeristy of Minnesota) and Henning Struchtrup (Univeristy of Victoria). In this work we consider a chain with a finite number of bi-stable elastic elements and study the dynamics of the system. We have obtained some interesting result and the results will be published in future.

Prepared papers during this year:

1. Y. Efendev and L. Durlofsky, “Numerical Modeling of Subgrid Heterogeneity in Two Phase Flow Simulations”, submitted to Water Resour. Res, 2001

2. Y. Efendiev, M. Luskin, H. Struchtrup and M. R. Zachariah, “Hybrid sectional model for coagulation and phase segregation in binary liquid nanodroplets”, submitted to Nanoparticle Res., 2001

3. Y. Efendiev and M. R. Zachariah, “A model for two-component aerosol coagulation and phase separation: A method for changing the growth rate of nanoparticles”, Chem. Eng. Sci, in press, 2001

4. Y. Efendiev and M. R. Zachariah, “Hybrid Monte-Carlo method for Simulation of Two-Component Aerosol Coagulation and Phase Segregation”, J. Colloid Inter. Sci., submitted, 2001

5. Y. Efendiev and M. R. Zachariah, “Hierarchical Hybrid Monte-Carlo method for Simulation of Two-Component Aerosol Nucleation, Coagulation and Phase Segregation”, to be submitted, 2001

6. Y. Efendiev, “Numerical modeling of formation invasion”, IMA Preprint

7. Y. Efendiev, “Exact upscaling of transport in porous media and its applications”, IMA Preprint

Selim Esedoglu IMA Postdoc Report for the 2000-2001 year

My first year at the IMA gave me an invaluable opportunity to broaden my perspective in the field of computer vision and, more generally, multimedia. By attending the workshops throughout the year, I acquainted myself with many different problems and methods of this wide field that I was not aware of before.

During the year, I devoted some of my time to preparing my Ph.D. thesis for publication. It studies a continuum limit for the Perona–Malik scheme, which is a numerical technique for de–noising digital images, under a certain scaling of the scheme's parameters with respect to the grid size. It has been accepted for publication in *Communications on Pure and Applied Mathematics*.

I had the opportunity to present my work at the following occasions:

- Contibuted Talks section of the Low Level Vision workshop at the IMA,
- P.D.E. Seminar at the Mathematics Department of Purdue University,
- Numerical Analysis Seminar at Courant Institute, New York University,
- Extended Dynamical Systems Minisymposium of the SIAM Conference on the Applications of Dynamical Systems (held in Snowbird, Utah).

Part of my research at the IMA has been directed at furthering the results obtained in my thesis. More specifically, I have been exploring the stability properties of the limiting continuum evolution described in my thesis. I expect that, among other things, my new results will allow me to remove or relax some of the conditions assumed in my first paper. I have been writing up this project; a preprint should be ready shortly.

Another problem I have been working on concerns dynamic issues related to the Mumford–Shah image segmentation functional. Image segmentation aims to automatically divide up a given image into relatively homogeneous regions separated by sharp boundaries. In the Mumford–Shah approach, the segmentation is obtained as the minimizer of an energy. In practice, the Mumford–Shah energy is approximated by more tractable energies that lend themselves to numerical minimization more readily. I have been investigating the gradient flows for such a class of approximating energies. In particular, I would like to understand what kinds of evolutions can arise as the limit of approximate gradient flows. So far, I have results for this problem in one space dimension.

Throughout the year, the workshops attracted a large number of more senior researchers in the field as visitors: another valuable opportunity for the postdocs. For example, I had the chance to meet and discuss at length my most recent progress with Prof. Antonin Chambolle, who was already familiar with my thesis work, both during the fall and the spring semesters.

Finally, in addition to organizing one semester of the IMA postdoc seminar (required from each postdoc), I was the co–organizer, along with Jianhong Shen, of the Multimedia and Data Analysis Seminar during the spring semester. In this latter seminar, the emphasis was on learning by presenting some recent and interesting papers in the field.

Annual report for the year September 1, 2000 – August 1, 2001

J. Gopalakrishnan

Work on efficient iterative techniques for Maxwell equations, a subject I started working on during my stay at IMA, has progressed. The paper "Overlapping Schwarz preconditioners for indefinite time harmonic Maxwell equations" (with J. E. Pasciak) which was submitted last year, is now accepted for publication in Math. Comp. A sequel to this titled "A multigrid algorithm for time harmonic Maxwell equations" (with J. E. Pasciak and L. Demkowicz) is now in preparation. Generous allocation of computing resources for this project from the Supercomputing Institute is gratefully acknowledged.

I have also been working on modeling cardiac ablation, a subject of interest to my industrial partner (Medtronic Inc.) and now to me as well. Ablation is a clinical procedure commonly used to treat cardiac arrhythmias. Last year was spent mainly on code development for this project. This year I have results from the code for endocardial catheter ablation. Motivated by the results of the code, I have taken up the problem of mathematically estimating heat transfer coefficients for a type of electrodes called irrigated catheter electrodes. I have preliminary but encouraging results using boundary layer asymptotics.

During the course of interactions with Medtronic engineers, I learned about a device called "pen electrode" that Medtronic recently started marketing. This is intended for epicardial ablation. A literature search revealed no models for this process. I have recently been able to come up with a mathematical model for this process, by obtaining an explicit approximate solution for fluid flow involved. This result is the subject of "A mathematical model for irrigated epicardial radiofrequency ablation", a paper in preparation.

I have also modeled a new device that Medtronic plans to market in future. Medtronic engineers were interested when results from the model were presented, and it is hoped that it will improve the final design of the device. These results are bound by a non-disclosure agreement with Medtronic, and will not be published. In regard to my projects with Medtronic, I gratefully acknowledge constant encouragement from Professor F. Santosa and especially his help in maintaining connections with Medtronic when my mentor there left the company midway.

With Guido Kanschat, a visiting postdoc at School of mathematics, I have written and submitted a paper titled "A multilevel discontinuous Galerkin method" to Numerische Mathematik. It deals with multigrid methods for efficient solution of the Poisson equation as well as a singularly perturbed advection-diffusion equation using discontinuous finite elements.

Bin Han IMA Postdoc Report for the 2000-2001 year

First, I'd like to express my great thanks to the IMA for its warmly hospitality, friendly and efficient staff, stimulating workshops in the program "Mathematica in Multimedia", many opportunities to interact with visitors and a very good research environment.

Overall, my stay at IMA was very productive and I benefited a lot from the program "Mathematics in Multimedia", in particular, the joint IDR-IMA workshop and the workshops on Geometric Design and Computer Graphics in April and May. The following are my activities during my stay at IMA.

I gave a talk in the IMA postdoctoral seminar on March 20, 2001. The title is *Subdivision schemes and biorthogonal wavelets by CBC algorithm*.

I participated in the Tenth International Conference on Approximation Theory at St. Louis March 26–29, 2001. I gave a 20 minute contributed talk in this conference. The title is: *A short overview of (wavelet) framelets III*. I also contributed a poster in this conference. The title of the poster is *Quincunx wavelets and projectable multivariate wavelets*.

I have been working on many problems in wavelet analysis and geometric aided design. The following is a short explanation of my research in this period.

1. From both theoretical interest and actual applications, it is of great importance to construct wavelet bases and tight wavelet frames with certain desired properties for a general dilation matrix. A simple and painless method called the projection method was proposed in [1]. Now for any dilation matrix, we can easily obtain interpolatory subdivision scheme, orthogonal wavelets and tight wavelet frames with any preassigned order of vanishing moments. In particular, the results in [1] can be used to design $\sqrt{3}$ subdivision schemes. There are very few general constructions on $\sqrt{3}$ subdivision schemes. As a particular case, [1] successfully proposed a family of such schemes and we are expecting to test such schemes in applications.

2. Multidimensional wavelets have to be used in many applications such as image/video processing, animation, subdivision volumes. However, there is a natural and fundamental question to be asked: by using high dimensional wavelets, what can we gain in comparison with the commonly used simply constructed tensor product wavelets. In [2], we successfully answered this question. In fact, we show that many multivariate wavelets, though they may be nonseparable (i.e., non-tensor product wavelets), do carry the tensor product structure. Consequently, in designing multivariate wavelets, the univariate wavelets do provide us some useful information to understand and design better real multivariate wavelets. Let us now discuss only one consequence of such result in [2]. In geometric aided design, the loop scheme has been widely used in many subdivision surfaces. Recently, based on the loop scheme, Khodakovsky, Schröder, Sweldens in *Progressive Geometry Compression, Proceedings of SIGGRAPH 2000* used a wavelet basis in the context of computer aided design to compress geometric data: meshes. The power of wavelet bases to greatly compress data was demonstrated in their paper. However, the ad hoc constructed wavelet basis in their paper is not compactly supported and it is still unknown whether such a wavelet basis is stable or not. These concerns may hurdle the efficiency or further improvement in wavelet-based compression techniques in CAGD. Now based on the result in [2] (thanks to the results in [2], we now have a better understand in designing good wavelet bases), we successfully design a compactly supported stable wavelet basis for the loop scheme (collaborating with Ingrid Daubechies at Princeton University, Wim Sweldens at AT & T labs, and Andrei Khodakovsky at Caltech). We are currently implementing our new scheme in the context of geometric design.

3. Subdivision schemes have been widely used in CAGD for subdivision surfaces. There are also a lot of papers in discussing various properties of subdivisions schemes: convergence, convergence rate and robustness. In [3], we found a unified approach so that many known results in the currently literature now can be easily proved and be better understood from this new angle of thoughts.

4. Though there are a lot of papers in the currently literature charactering the smoothness of multivariate refinable functions, there are very few practical ways to compute the smoothness exponent, especially when the support of the function is large, or when the dimension goes to 2D or 3D. Smoothness is one of the most important properties of a wavelet system. In [4], by taking into account of the symmetry of the refinable function, we can greatly reduce the size of the problem and efficiently compute the smoothness exponents of many multivariate refinable functions. We can compute the smoothness exponents for many refinable functions which can not be easily handled by the current known methods.

5. Interpolatory subdivision schemes are very important in subdivision surfaces. However, the currently known schemes such as the Butterfly scheme (proposed by Dyn, Levin and Gregory) have serious problems: the constructed subdivision surfaces have unpleasant ripples. In order to overcome this problem, we can try Hermite refinable functions; that is rather than use one single function, we now can use three functions. In [5], we found several very interesting bivariate Hermite schemes. The work in [5] has been motivated after discussing with two other visitors in IMA: Thomas Yu (participant of the joint IDR-IMA workshop in April) and Nira Dyn. Collaborating with Thomas Yu, we are now exploring such new 2D Hermite schemes in subdivision surfaces to obtain better interpolatory subdivision surfaces by eliminating the problem of ripples in the Butterfly.

Currently, I am working with Nira Dyn (visitor at IMA) on several problems such as fairness of subdivision surfaces, new interpolatory subdivision schemes and new Hermite subdivision schemes. Initial interesting results have already been obtained and we are planning to continue this collaboration in the future. At the meantime, I am also work with Ingrid Daubechies, Wim Sweldens and Andrei Khodakovsky to implement several wavelet bases to do geometric compression in CAGD. Collaborating with Dr. Jian-Liang Qian (postdoc at IMA), we are trying to find some efficient numerical ways to further improve the procedures for computing the smoothness exponents of refinable functions.

In summary, I have learned and benefitted a lot from the workshops in the program " Mathematics in Multimedia", in particular, the part on geometric design and computer graphics. I am planning to continue my research in wavelet applications in CAGD and computer graphics. For examples, I am now considering to design subdivision schemes and wavelet bases which are particularly useful in animation and subdivision volumes. Thanks to IMA, my research at IMA is very productive and I feel my research has been fueled to explore many interesting problems.

Papers written and submitted from January 2001 to May 2001. Support from IMA was gladly acknowledged in all of the following papers.

1. B. Han, *Symmetry property and construction of wavelets with a general dilation matrix*, submitted to Linear Alg. Appl., IMA preprint 1755

2. B. Han, *Projectable multivariate wavelets*, submitted to Appl. Comput. Harmon. Anal., IMA preprint 1756

3. B. Han, *The initial functions in a subdivision scheme*, submitted to Approximation Theorem X (Conference proceeding edited by C. A. Chui, L. L. Schumaker and J. Stoeckler).

4. B. Han, *Computing the Smoothness Exponent of a Symmetric Multivariate Refinable Function*, submitted to SIAM J. Matrix Anal. Appl.

5. B. Han, *Examples of bivariate Hermite spline refinable functions*, ready to be submitted.

The Annual Postdoc Report 2000-2001
Takumi Hawa

1 IMA Workshops and other Programs

- Attending IMA workshops, seminars, and tutorials as an IMA postdoctoral candidate was an excellent learning experience for me to have a latest both engineering and mathematical problems and technique. Having conversation with both short and long term visitors were useful opportunities for me as well. Giving a talk in the outside conferences were also great opportunities to have other people's opinion, especially from engineers and experimentalists.

2 TEACHING EXPERIENCE

- I taught a pre-calculus course as an instructor at the University of Minnesota in Fall 2000. Even though my students were not science and engineering majors, I showed them the connection between mathematics and physics, and succeeding in raising their motivation to learn. I was successful in establishing interactive environment for the students in my course. I really enjoyed teaching.

The summary of my work as an IMA postdocral candidate can be seen below.

3 WORK & COLLABORATIONS

- ”Viscous flow in a symmetric and a slightly expanding channel” with a mentor Prof. Weinberger, H. in the Department of Mathematics in U of Minnesota.
- ”Effects of corner singularities and plate thickness on the flow around two-dimentional obstacles” writing proposal with Prof. Durst, F. in Institute of Fluid Mechanics (LSTM), University of Erlangen-Nuremberg, Germany. We wrote a research proposal to the Humboldt Research Fellowship.
- ”Numerical-asymptotic expansion matching for computing a viscous flow around a sharp corner,” with Prof. Rusak, Z. in the Department of Mechanical Engineering, Aeronautical Engineering and Mechanics in Rensselaer Polytechnic Institute (RPI). We had several discussions at APS/DFD, Washington DC, November, 2000 and over the phone.
- ”Viscous flow in a symmetric channel with a sudden contraction,” with Prof. Rusak, Z. in the Department of Mechanical Engineering, Aeronautical Engineering and Mechanics in RPI. We had several discussions at APS/DFD, Washington DC, November, 2000 and over the phone.
- ”Detonation evolution due to an initial temperature gradient,” with Prof. Kapila, A. and Prof. Schwendeman D. in the Department of Mathematical Sciences in RPI since the first workshop at IMA.
- ”Molecular dynamics simulation of nanoparticles,” with Prof. Zachariah, M. and Prof. Truhlar, D. in the Center of NanoEnergetic Research in U of Minnesota. (started in June 2001).

4 PUBLICATIONS

Major Articles

- "The dynamics of a viscous flow in a channel with a sudden expansion," Hawa, T. and Rusak, Z., *Journal of Fluid Mechanics,* **436**, pp.283-320, 2001.
- "Viscous flow in a slightly asymmetric channel with a sudden expansion," Hawa, T. and Rusak, Z., *Physics of Fluids,* **12**, 9, pp.2257-2267, September 2000.

Articles Under Review

- "Detonation evolution due to an initial temperature gradient," Kapila, A., Schwendeman D., Quirk, D., and Hawa, T., *IMA Proceedings,* (in preparation).
- "Numerical-asymptotic expansion matching for computing a viscous flow around a sharp corner," Hawa, T. and Rusak, Z., *Theoretical and Computational Fluid Dynamics,* (submitted in August 2000).

Articles in Non-Refereed Conference Proceedings

- "The dynamics of detonation due to an initial temperature gradient," Hawa, T., Schwendeman D., and Kapila A., Bulletin of American Physical Society, 45, (9), 148, November 2000.

Research Proposal

- "Effects of corner singularities and plate thickness on the flow around two-dimensional obstacles," Alexander von Humboldt Research Fellowship (submitted in March 2001).

5 PRESENTATIONS

- "Viscous flow in a symmetric channel with a sudden expansion," Hawa, T., Department of Mechanical Engineering and Applied Mechanics, U of Rhode Island, April 19, 2001.
- "Emergence of detonation due to an initial temperature gradient," Hawa, T., Schwendeman, D., and Kapila, A., APS/DFD, Washington DC, November 20, 2000.

Yong Jung Kim IMA Postdoc Report for the 2000-2001 year

My second year as a postdoctoral member of the IMA was a productive one so far. The project on the metastability in reaction-diffusion equations had the first result, a joint work with A. E. Tzavaras (U of WI) [1], accepted by SIAM. The project has been continued as a joint work with Wei-Ming Ni (U of MN) [2], which is about to be submitted. The work with Shi Jin (U of WI) regarding the instability of roll waves modeled by $u_t + uu_x = u, u(x,0) = u_0(x)$ and a numerical scheme for it has been published recently [3]. I also found a new collaborator, Bernardo Cockburn (U of MN). He invited me to his project for error estimation for nonlinear hyperbolic conservation laws [4]. In the project we consider a posteriori error estimates for discontinuous solutions for the scalar equations with general diffusion and reaction terms in multi-dimensional space.

The most exciting part in my research during my second year in IMA is the development in the theory of the piecewise self-similarity solutions to conservation laws. The potential of such a solution has been found during my first year. The discussions with other IMA postdoctoral members and visitors like R. DeVore and B. Lucier were very helpful in the development. In the first article [5] the basic idea and properties are introduced together with numerical examples. In the scheme the exact solution is achieved through the self-similarity summations among base functions without time discretization and, hence, we can possibly construct a scheme of complexity order $O(N)$, not $O(N^2)$. This method also has the strength as a analytical tool in the study of long time behavior. In [6] we establish an optimal L^1 convergence rate to N-waves. This project should be an continuing one for a while. There are several prospects and mysteries. Here I want to remark one of them. The front tracking method for a scalar problems can be completely rewritten in this point of view, which is simpler and stronger. But for the systems it is hard to answer. It seems like extensive efforts needed to explore this possibility as it has been required in the development for the front tracking method.

References

[1] Y.-J. KIM AND A. E. TZAVARAS, *Diffusive N-waves and Metastability in Burgers equation*, SIAM J. Math. Anal., to appear.

[2] Y.-J. KIM AND W.-M. NI *Convergence rate of the Burgers equation to N-waves*, preprint.

[3] S. JIN AND Y.-J. KIM, *On the computation of roll waves*. Math. Model. Num. Anal. 35 (2001), 463–480.

[4] B. COCKBURN, *A simple introduction to error estimation for nonlinear hyperbolic conservation laws*. preprint, ftp://ftp.math.umn.edu/pub/misc/cockburn/ee.ps.gz

[5] Y.-J. KIM, *Piecewise Self-similar Solutions and a Numerical Scheme for Scalar Conservation Laws*. (Siam J. Numer. Anal., submitted)

[6] Y.-J. KIM, *Piecewise Self-similar Solutions and Asymptotic Behavior in Scalar Conservation Laws*. preprint.

Dimitri Kirill IMA Postdoc Report for the 2000-2001 year

For the 2000-2001 year, I've continued research work on the chemical-mechanical polishing (CMP) modeling problem (Motorola industrial project), and have begun to attack some loose ends related to my older graduate thesis work—specifically, fully-nonlinear simulation of stressed rods undergoing elastic-strain- and capillarity-driven surface diffusion. Several papers are in the process of being written, or close to being submitted. One of these is joint work with my former graduate advisors (Northwestern Univ.) dealing with diffusional instabilities in stressed pores and tubules, and the other paper is in collaboration with my industrial mentor at Motorola (Len Borucki).

On the CMP side: work continues on understanding the lastest experimental results coming from the Georgia Tech CMP team, and trying to model these using a combination of viscoelastic pad deformation, polishing-head tilt and force/moment balance, and lubrication theory for rough surfaces. This is joint work with Dr. Len Borucki, senior scientist at Motorola, Inc. Only recently has the importance of having a nearly flat polishing pad (within 10 micron tolerance) been fully recognized. Recently, the Georgia Tech experimental team has made special efforts to planarize both polishing head and pad down to micron tolerances (a remarkable feat). This has resulted in much more consistent and uniform experimental results. The most recent (May '01) set of experimental results from G.I.T. appears to reveal the strong influence of pad viscoelasticity in determining hydrodynamic fluid pressure data. We're currently trying to understand/model this data.

On the "surface diffusion" problem side: I'm attempting to attack the fully-nonlinear evolution problem by reducing the elastic field problem to a boundary integral equation, and then using boundary (surface) elements (triangulated elements, perhaps) to evolve the surface. Bearing in mind that a perturbed, stress rod will most likely evolve towards some sort of pinch-off, special precautions must be taken to re-mesh the evolving surface, especially in regions of high curvature (i.e., near pinch-off point). Also, I'm looking into the possibility of doing a weakly-nonlinear (near threshold) stability analysis of certain corkscrew instabilities which are observed in the case of the stressed solid rod.

Annual Postdoc Report for 2000-2001. of Alexei Novikov

As a second year Postdoctoral Member of the IMA during the year on Mathematics in Multimedia my main responsibilities included attending workshops, seminars and tutorials. This provided a unique opportunity for me to gain a broad perspective on applications of the theory of Partial Differential equations and the Numerical Analysis to problems in Vision, Speech, Geometric Design and Computer Graphics. I have learned invaluable insights to better understanding of different approaches to real-world problems by communicating with a versatile scientific community of engineers, physicists, mathematicians from industry, research institutes and universities.

In the fall, I was a lecturer for a course “Linear Algebra and Differential Equations using MATLAB”. This was a class with about one hundred students majoring in engineering. My responsibilities include two weekly lectures, office hours, design of exams and midterms, distribution of grades. I also visit weekly laboratory sessions, design and update the class web-page, hold review sessions.

In the whole year I continued a collaboration with Leonid Berlyand on Variational Methods for the problems of effective conductivity of high-contrast composites. A paper on the behavior of the effective conductivity when there are inhomogeneities in the composite is to be sent for publication shortly.

I continued to work on problems of multiscale analysis in Fluid Dynamics. A directly related to this topic paper “Eddy viscosity of cellular flows” with G. Papanicolaou has been accepted to Journal of Fluid Mechanics. Another related result of a rigorous proof of convergence and uniform boundedness of solutions of nonlinear modulational perturbations of cellular flows in the homogenization limit was presented at the conference “Solutions of Partial Differential Equations in Periodic Media” in University of Arkansas. I plan to finish the paper with this result over the summer.

I began working on harmonic analysis methods for PDE’s of Fluid Dynamics. I will be giving review talks on these methods for KdV equations at the UCLA summer school on Fluid Dynamics in Asilomar.

During by stay at IMA I was fortunate to be able to communicate with members of the Department of Mathematics, University of Minnesota. I have met with my mentor professor Vladimir Sverak biweekly and discussed regularity theory for Navier-Stokes and Schroedinger equations. Professor Bernardo Cockburn was helpful in discussions about numerical methods. I gave a talk and the seminar on partial differential equations on eddy viscosity of cellular flows after which I had some interesting discussions with professors Walter Littman and Hans Weinberger.

I am convinced that the experiences which I gained during the year will be very useful in my later career, whether in academics or in industry. I would like to thank organizers of the IMA program, the IMA administrative staff, and my fellow postdocs for that.

Annual Postdoc report for 2000-2001 of Nilima Nigam

I would like to thank the IMA for my appointment as an Industrial Postdoctoral associate during this past year, and for providing me with intellectual and institutional support for my research.

My activities this year fell into the following 4 categories:

1. Learning about, and research in, micromagnetics
2. Continuing research effort in variational methods for PDE
3. Coding effort for Seagate corporation
4. Collaborative effort with Prof. Debra Lewis

A major aspect of my work this year continued to be in numerical micromagnetics. In the course of learning about numerical micromagnetics, I discovered that a major computational expense was in computing a potential field. Thanks to a suggestion from Prof. Fernando Reitich, my IMA-apponted mentor, I learnt about the Fast Multipole Algorithm (due to Rokhlin and Greengard).

The project with Seagate involved developing a code to study the effects of geometric variations of a read-head on magnetic characteristics. To this end, I modified a code by Nabors, Korstmeyer, and White to be used in conjunction with a time-stepping algorithm for numerical micromagnetics. Previous codes were only able to handle rectangular geometries; the use of the fast multipoles enabled me to study larger structures with curved geometries. Several issues relating to large-scale computations arose during the code development, and I have received a lot of constructive help from the IMA in this regard. A report was submitted to Seagate about the use of this code in May 2001, and a joint report is in preparation, [10]

Conventional time-stepping algorithms do not sufficiently preserve certain physical quantities. To resolve this issue, I have worked with Prof. Debra Lewis of UC Santa Cruz on developing an efficient Lie-group integrator of the RKMK class for micromagnetics. This has been a collaboration begun last year we have developed a geometric time-stepping algorithm for micromagnetics ([6, 5]). Along with Prof. Peter Olver, we applied for a Focussed Research Group NSF grant for further investigations in this direction. This work is truly interdisciplinary, since geometric algorithms have not been tested on large-scale, highly nonlinear problems such as this.

An interesting off-shoot of this work is a collaborative effort with Prof. Peter Monk at the University of Delaware. This work involves a combind fast-multipole and finite-element method, [7], which is a modification to another collaborative effort, [1].

My thesis work was concerned with variational methods for exterior problems ([8, 9]), and I am collaborating with my thesis advisor, Prof. G.C. Hsiao on extensions of this topic. ([3, 2, 4]).

I would like to acknowledge the supportive environment of the IMA for research and collaboration, and for the numerous learning opportunities I have been offered.

Grant proposal

Submitted an NSF Focussed Research group proposal with Prof. Debra Lewis and Prof. Peter Olver. Here is a description of the proposal from the abstract:

Application of geometric integration techniques to micromagnetics

Project Summary: This project will investigate the applicability of Lie-group methods, augmented by moving-frame theory, to numerical micromagnetics, and thus requires the collective expertise of the PIs in computational micromagnetics, applied mathematics, and geometrical analysis.

The physical model describes the evolution of the magnetization under a nonlinearly changing effective field, which suggests the use of geometrical methods for resolving their trajectories. We will initially examine the underlying geometrical structure of the micromagnetics model, then construct time-stepping algorithms which preserve it. We will subsequently study the stability and efficiency of these methods, to provide consistent, accurate and competitive tools for computation. A key theoretical issue is the development of a discrete moving-frame theory suitable for these non-linearly interacting systems.

Initial investigations on simple examples reveal exciting possibilities for improvement in the accuracy of the integrator, achieved by carefully conserving invariants of the system. Future work also includes extending these methods of analysis to other systems which exhibit similar underlying geometrical structures.

A key feature of this project is the synthesis between theoretical studies and computational experiments, each one directly impacting and motivating the other. Deeper understanding of the invariants of the physical system will allow us to design better algorithms, while results from numerical experiments will promote further theoretical analyses. There are many challenging problems in the interface of material science and geometrical integration, and this project will lay the groundwork for future research in this direction.

Conferences/Seminars 2000-2001

1. Material Science and Homogenization conference, Akron, Ohio, September 2000.
2. Seagate research conclave, Minneapolis, Dec 2000. *recent results in numerical micromagnetics*
3. Numerical Analysis seminar, U. of M, March 2001,*An overlapping method for time-harmonic electromagnetic scattering*
4. IMA Postdoc seminar, March 2000, *Scattering Theory*
5. Conference on micromagnetics May 2001, Princeton. *Efficient Micromagnetic Calculations*

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[2] G. Hsiao and N. Nigam, *"a problem in fluid-structure interactions"*. submitted, 2000.

[3] G. Hsiao and N. Nigam, *"a transmission problem in the exterior of a thin domain"*, Quaderni di Matematica, (2000). "Proceedings in memory of G. Fichera".

[4] G. Hsiao and N. Nigam, *"an interesting result regarding propagation of elastic waves in thin shells"*. in preparation, 2001.

[5] D. Lewis and N. Nigam, *A higher-order lie group integrator for micromagnetics*. in preparation.

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[7] P. MONK AND N. NIGAM, *A combined finite element-fast multipole method for approximating the time-harmonic maxwell system.* in preparation, 2000.

[8] N. NIGAM, *A variational method for acoustic scattering from a thin penetrable shell*, IMA preprint series, 1719 (2000).

[9] ——, *A variational method in acoustics related to an impenetrable scatterer coated by a thin penetrable shell*, in SIAM Waves Conference Proceedings, 2000, SIAM, 2000.

[10] L. X. WANG AND N. NIGAM, *"a fast algorithm for 3-d micromagnetics computations"*. in preparation for submission to the IEEE, 2001.

Annual Postdoc Report for 2000-2001 of Jianliang Qian

As a first year IMA postdoctoral member for the thematic year "Mathematics in Multimedia", I have actively participated in various activities, including workshops, seminars and tutorials. This provided me with an excellent opportunity to broaden my views of how the mathematics plays a role in the modern multimedia age.

During the course of the year, I have also become aware of some new application areas, such as level-set evolution theory for image processing, viscosity solution for image analysis related PDEs, inverse problems for EEG and MEG based on Maxwell equations, just to name a few that come to my mind right away. Of course, I also liked listening to the other applications of various techniques and methods in Multimedia, such as geometrical design and computer graphics.

Aparting from the IMA workshops and seminars, I also took part in IMA Postdoc Seminar and the Applied Mathematics Seminar of School of Mathematics. During the Spring quarter, I was in charge of organizing the Postdoc seminar; I invited several well-known professors in the field to give talks at the Postdoc Seminar: Prof. Wolfgang Dahmen at RTH, Aachen who spoke on "Adaptive wavelet methods", Prof. Adam

Lutoborski from Syracuse University who told us about "Numerical methods for the procrastus problem", Prof. Paul Garret from School of Mathematics who spoke on " Overview of Rijndael, the new Advanced Encryption Standard". Besides those senior visitors, I also invited other junior visitors to speak on their researches. Of course, I also gave a talk at Postdoc Seminar during the fall quarter. In addition, I was invited to give a talk at the Applied Mathematics Seminar at the School of Mathematics and at the Applied Mathematics Seminar at Michigan State University.

As for my research accomplishments for this year, it is pretty fruitful. I have finished three papers and one in preparation; in addition, I have three papers accepted to publish in Geophysics and Wave Motion and one under review for Journal of Computational Physics:

Qian and Symes, "Paraxial geometrical optics for anisotropic quasi-P waves: theories and numerical methods," accepted by **Wave Motions**, 2001.

Qian and Symes, "Paraxial eikonal solvers for anisotropic quasi-P traveltimes," submitted to **Journal of Computational Physics**, 2001.

Qian and Symes, "An adaptive finite-difference method for traveltimes and amplitudes in isotropic media," to appear in **Geophysics**, 2001.

Qian and Symes, "Finite-difference quasi-P traveltimes for anisotropic media," to appear in **Geophysics**, 2001.

Specifically I have been collaborating other researchers on several different projects. The first project is continuation of my thesis work. I developed a full aperture eikonal solver for quasi-P waves in anisotropic media. There are already two papers out of this project:

Qian, J., Symes, W. W. and Dellinger, J., "A full aperture eikonal solver for quasi-P traveltimes," submitted to SEG at San Antonio, TX, 2001.

Qian, J. and Symes, W. W., "A paraxial formulation for the viscosity solution of quasi-P eikonal equations," to be submitted.

The second project is a priori error estimates for monotone schemes for Hamilton-Jacobi (HJ) equations. This is a collaboration with my mentor, Prof. Bernardo Cockburn, School of Mathematics. We analysed monotone schemes for HJ equations by using a technique, so-called paraboloid test. We plan to use these techniques to tackle second-order nonlinear PDEs also. Products of this research are:

Cockburn, B., "A priori error estimates for monotone schemes for Hamilton-Jacobi equations", to be submitted.

The third project is on optical waveguide and near-field optics with Professor Fadil Santosa of IMA and Professor Gang Bao at Michigan State University. This is a ongoing project.

In addition, I had several interesting conversation with Dr. Jim Berryman at Lawrence Livermore National Lab and Professor Clement Yu at University of Chicago. They were both willing to share their ideas with me on different applied mathematics issues.