# UT Austin | Portugal

## International Collaboratory for Emerging Technologies, CoLab

## Annual Report 2009-2010: MATHEMATICS


INTERNATIONAL COOPERATIVE RESEARCH AND EDUCATION: Year 4 of 5

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# UT Austin | Portugal CoLab:
# MATHEMATICS

## Strategy

As the UT Austin | Portugal CoLab program completes its fourth year, the Mathematics group has a strong sense of achievement and confidence for the final phases of the program. Education and research initiatives such as the yearly workshops in Austin, summer schools and workshops in Portugal, research training groups for undergraduates, the PhD and post-doctoral programs, as well as the exchange faculty program have been extremely successful.

This academic year, several Portuguese faculty spent extended periods at The University of Texas at Austin. In September 2009, Agnieska Malinowska and Delfim Torres from University of Aveiro visited Austin and laid the groundwork for a research project with UT's Cristina Caputo. Daniel Abreu, from UCoimbra, worked closely with John Gilbert at the Mathematics Department of UT; and Professor Isabel Figueiredo, UCoimbra, spent several months in residence at UT.

AnApplications for post-doctoral positions resulted in visits by Stefania Patrizi and Maria Teresa Perez Perez to the UT Department of Mathematics where they are in residence for the fall semester. Further, the final research call brought funding to new projects to that we believe are critical to establishing long term research collaborations with UT.

A third annual workshop, *Classical and Random Dynamics in Mathematical Physics,* was held which brought together several Portuguese researchers with UT Austin faculty. Also in Coimbra, the third Summer School and Workshop focused on Imaging Sciences and Medical Applications, expanding on a selected range of interdisciplinary topics handled from both a mathematical and an engineering applications point of view. In addition to mathematicians and engineers, the target audience included graduate and PhD students with a research interest in problems related to Mathematics, Medical Imaging, Biomechanics, Biology, and Bioengineering.

Events scheduled, but still pending, include the Postdoctoral Academy in Mathematics to be held September 23-24, 2010 at the Universidade Nova de Lisboa; and "Optimization in Machine Learning" to be held at the University of Texas at Austin, May 31 to June 7, 2011.

Diogo Gomes , Luís Caffarelli

Diogo Gomes, Director CoLab Mathematics Program, Portugal; Principal Investigator, Project: Applied Mathematics

Luis Cafarelli, Director CoLab Mathematics Program, Austin; Co-Principal Investigator, Project: Applied Mathematics

# RESEARCH

## Project: Applied mathematics from dynamical systems to cryptography

*Principal Investigators:*

1. Diogo Gomes, IST
2. Luis Caffarelli, The University of Texas at Austin

*UT Austin Research Team*

3. Irene Gamba
4. William Beckner
5. Jose Felipe Voloch
6. Rafael de la Llave
7. Thaleia Zariphopoulou

*Portuguese Research Team*

8. A. Malinowska
9. Amílcar dos Santos Costa Sernadas
10. Carlos Alberto Varelas da Rocha
11. Carlos Manuel Costa Lourenço Caleiro
12. Cláudia Rita Ribeiro Coelho Nunes Philippart
13. Delfim Fernando Marado Torres
14. Joao Carlos Martinho Lopes Dias
15. Panagiotis Souganidis, University of Chicago
16. Paulo Alexandre Carreira Mateus
17. Raquel Maria Medeiros Gaspar
18. Verónica Rita Bolseiro, Graduate researcher, PhD candidate
19. Gabriele Terrone Bolseiro, Graduate researcher, PhD candidate
20. Filippo Cagnetti, Post-doctoral researcher
21. Milena Chermisi, Post-doctoral researcher
22. Maria Teresa Perez Perez, Post-doctoraal researcher
23. Stefania Patrizi, Post-doctoral researcher
24. Farid Borzognia, Post-doctoral researcher
25. Levon Nurbekian, Graduate researcher, PhD candidate
26. Diego Marcon Farias, Graduate researcher, PhD candidate
27. Sérgio Pequito, Graduate Researcher, PhD candidate

*The Project*

Researchers from several disciplines are joining efforts in applied mathematics including dynamical systems, financial mathematics, game theory, optimal control, viscosity solutions, number theory, and cryptography. In dynamical systems the main focus research areas are Aubry-Mather theory, renormalization and attractors of semilinear parabolic equations. In financial mathematics focus is being placed on developing forward price models, interest rate models and stochastic volatility models, and first passage times in diffusion processes. Game theory oligopoly models are being considered to investigate the following issues: uncertainty, signaling, dynamic price discrimination (linear prices and non linear pricing), research and development programs, location decisions, advertising strategies and their effects, trade policy models and competitive strategies in spatial networks, as well as mean-field games and its applications. Optimal control theory and viscosity solutions of Hamilton-Jacobi equations are essential to understand important problems in dynamical systems (Aubry-Mather theory) and in mathematical finance. These directions are being pursued, as well as certain problems in multiple criteria decision-making. Finally, in the emerging applied area of cryptography, the group is examining post-quantum cryptography in order to propose cryptosystems based on rational points on curves over function fields and show that they are robust to quantum adversaries.

*Research metrics*

*Start date:* September 1, 2009 *End date:* August 31, 2012

To help initiate this joint research, D. Gomes, D. Torres and A. Malinowska visited The University of Texas at Austin. During these visits, research on Partial Differential Equations and in Optimal Control Theory was actively pursued. We expect Gordan Zitkovic to visit Lisbon this September to pursue research activities under this project on Stochastic Processes and Stochastic Optimal Control. D. Gomes and G. Terrone have submitted a paper on Bernstein estimates for weakly coupled elliptic equations. D. Torres, A. Malinowska, and C. Caputo initiated collaboration during the stay of D. Torres and A. Malinowska during September 2009. A paper has been submitted. V. Quítalo has been pursuing research under L. Caffarelli and D. Gomes on Fully Nonlinear equations.

William Beckner, UT Austin Research Team, Project: Applied Mathematics

## Project: Endoscopic image processing through mathematic modeling

*Principal Investigators:*

1. Isabel Maria Narra de Figueíredo, U Coimbra
2. Omar Ghattas, The University of Texas at Austin

*UT Austin Research Team*

3. Georg Stadler, Faculty researcher
4. Bjorn Engquist, Faculty researcher
5. Yen-Hsi Richard Tsai, Faculty researcher
6. Chandrajit Bajaj, Faculty researcher

*Portuguese Research Team*

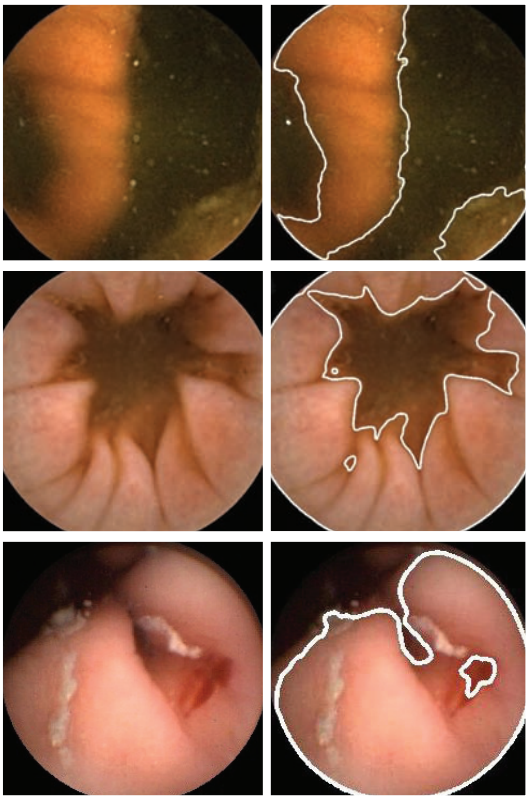
7. Carlos Manuel Franco Leal, UCoimbra FCT researcher
8. Giuseppe Romanazzi, UCoimbra FCT researcher
9. Juan C. Moreno Briceño, UCoimbra FCT doctoral researcher
10. Surya Prasath, UCoimbraFCT postdoctoral researcher
11. Pedro Manuel Narra de Figueiredo, UCoimbra FM researcher
12. Maria Manuel Rodes de Sousa Romão Donato, UCoimbra FM researcher
13. Sandra Maria Fernandes Lopes, UCoimbra FM researcher
14. Nuno Miguel Peres de Almeida, UCoimbra FM researcher
15. João Manuel Ribeiro da Silva Tavares, UPorto Faculty researcher
16. Zhen Ma, UPorto Graduate researcher
17. Ilda Marisa de Sá Reis, UPorto Graduate researcher
18. Mário Alexandre Teles de Figueiredo, UTL Faculty researcher
19. José Manuel Bioucas Dias, UTL Faculty researcher
20. Elisha Rabinovitz, Chief Scientist, Consultant Given Imaging

Isabel Figueiredo, U Coimbra, Principal Investigator for Project Endoscopic image processing.

*The Project*

This project focuses on the mathematical modeling and endoscopic imaging processing of aberrant polyps and aberrant crypt foci (ACF, which statistically precede polyp formation). Multiscale methods are used in a modeling process which involves partial differential equations and level set methods, to simulate the dynamics and shape of ACF and polyps populations. The project's aim in image processing is to develop computerized and fast algorithms to identify and assess ACF and polyps patterns, captured in vivo by endoscopy in order to facilitate and speed up screening methods towards CRC prevention. The DM-FCTUC and FM-UC teams at U Coimbra have focused their research so far on the image segmentation of endoscopic aberrant crypt foci. Their ongoing research includes:

- Image detection of colorectal polyps obtained with the PillCam colon capsule (produced by the company Given Imaging), either static or video images (the techniques employed involve variational methods, partial differential equations and optimization).
- Mathematical analysis for simulating the dynamics and shape of aberrant crypt foci and colorectal polyps' populations, by means of time dependent equations for cell populations (the techniques include convection-diffusion equations and level set methods).



Endoscopic images, with image segmentation shown on the right.

The teams of FEUP and IT have developed research in imaging sciences which is not yet directly related to the main topics of this project. However, their work is of course extremely important in itself, not only because it fits the framework of the project, but also because the techniques developed might be applicable and meaningful to the particular medical problem of the project.

In the period July 01, 2009 to March 31, 2010, the U Coimbra team developed some effective research collaboration with the following project members of UT Austin: Georg Stadler, Omar Ghattas, Bjorn Engquist and Richard Tsai. In particular, Isabel Figueiredo visited ICES, UT Austin, from August 30 to October 2, 2009, and also from March 1 to May 7, 2010; she has returned this fall, having arrived August 27, and plans to continue her collaborations in residence at the Institute for Computational Engineering & Science (ICES), until October 2, 2010. Bjorn Engquist of UT Austin visited the Department of Mathematics, University of Coimbra, from November 2 to 4, 2009.

*Research metrics*

*Start date:* July 1, 2009 *End date:* June 30, 2013

The following research advancements related to the project have been accomplished by team members:

- Publications in progress: 4
- Papers published or in press: 9
- Communications in Congresses/Scientific Meetings (PT members): 7
- Seminars in PT: 1
- Presentations at organized events: 3

## Project: Nonlinear partial differential equations

*Principal Investigators:*

1. José Miguel Urbano, U Coimbra
2. Luís Caffarelli, UT Austin
3. Irene Gamba, UT Austin

*UT Austin Research Team*

4. Alexis F. Vasseur, UT Austin
5. Ana Jacinta Pereira da Costa Soares, UMinho
6. Clint Dawson, UT Austin

*Portuguese Research Team*

7. Bruno Miguel Almeida Martins Pereira, UTL PhD candidate
8. Celestino António Maduro Coelho, UTL PhD candidate
9. Domingos José Ramos Lopes, U Coimbra PhD Student
10. Euclides Augusto Luís, UTL PhD candidate
11. Eugénio Alexandre Miguel Rocha
12. Eurica Manuela Novo Lopes Henriques
13. Fabio Augusto da Costa Carvalho Chalub, UNL
14. Fernando Augusto Pinto Miranda, UMinho
15. Filipe Serra de Oliveira, UNL
16. Hugo Ricardo Nabais Tavares, UL PhD candidate
17. João Pedro Silva Brito Boto, FC/UL
18. Juha Hans Videman
19. Lisa Maria de Freitas Santos
20. Miguel de Paula Nogueira Ramos FC/UL
21. Pedro Alves Martins da Silva Girão
22. Rojbin Ozlem Laleoglu
23. Susana Margarida Pereira da Silva Domingues de Moura

*The Project*

Nonlinear partial differential equations (PDEs) are central in modern applied mathematics, both in view of the significance of the concrete problems

they model and the novel techniques that their analysis generates. This project explores some of the new applications of these equations in biomathematics, against eight tasks:

- Regularity for singular/degenerate PDEs
- Numerical ocean and climate modeling
- Nonlinear elliptic systems
- Kinetic equations and BGK-type models
- Problems driven by subelliptic operators
- Drift-diffusion equations
- Free boundary problems
- PDEs involving variable exponents.

Advancement in understanding of these equations can be related to many applications such as the motion of multiphase fluids in porous media, the melting of crushed ice (and phase transitions in general), the behavior of composite materials, the pricing of assets in financial markets, or the quantum drift diffusion in semiconductors.

To date, in joint work with Vorotnikov, Urbano proved a series of results concerning the emptiness and non-emptiness of a certain set of Sobolev functions related to the well-posedness of a two-phase minimization problem, involving both the *p(x)*-norm and the infinity norm. The results, although interesting in their own right, hold the promise of a wider applicability since they can be relevant in the context of other problems where minimization of the p-energy in a part of the domain is coupled with the more local minimization of the infinity norm on another region.

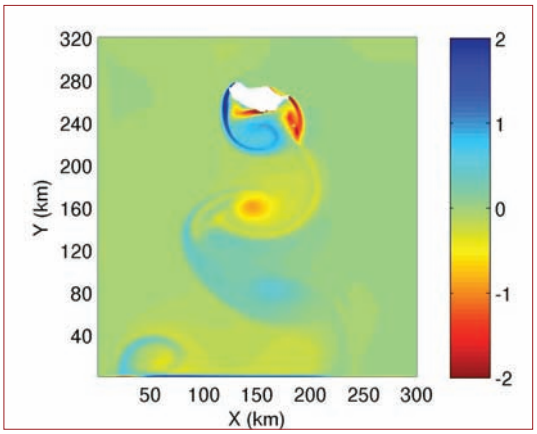
In relation with Bose-Einstein type systems for binary mixtures, the existence of positive solutions for such systems was obtained (B.Noris and M. Ramos) and the properties of the limit configurations was undertaken (H. Tavares, S. Terracini, et al.).

The trend to equilibrium of a chemically reactive mixture modelled by means of the spatially homogenous Boltzmann equation has been investigated by A. J. Soares and F. Oliveira. Under the assumption of uniformly boundedness and equicontinuity of the distribution functions, the solution of the Boltzmann equation is shown to converge in strong *L 1*-sense toward Maxwellian equilibrium as time becomes large. This research work has been developed in collaboration with G. M. Kremer (Univ. Federal do Paraná, Brazil).

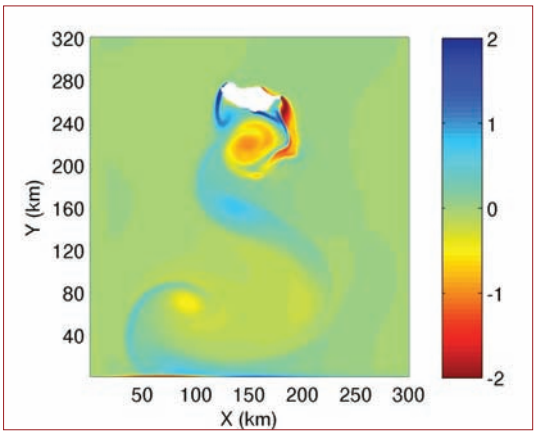
Pending research includes the study of the regularity question for infinity harmonic functions by means of intrinsic scaling; and to approach the evolutionary infinity Laplace equation using its discrete version, in which the objective is to obtain a new proof of the existence of solutions and, most importantly, to derive more direct Lipschitz estimates and an obvious way of constructing a numerical scheme, similar to the Oberman scheme for the stationary equation. This could provide insight on how to deal with the non-homogenous stationary problem when the non-homogeneous term changes sign, a major difficulty in the theory.

Researchers intend to obtain a rather complete study of the ground state solutions of strongly nonlinear elliptic systems, including: their sign, uniqueness, and radial symmetry, which is being performed jointly with D. Bonheure (ULB, Brussels) and E. dos Santos (Univ. Sao Carlos, Brazil)).

The global existence and stability of solutions for space homogeneous chemically reactive gases will be investigated for models of simple reactive spheres. This work will be developed in collaboration with Jacek Polewczak (California State Univ.). Also, free boundary problems will be examined, in regards to the existence of a solution and the asymptotic behavior in time will be analyzed for the evolutionary system coupling the electromagnetic and thermal fields associated with power type laws both in the electromagnetic induction and Joule heat. Some progress has




The normalized relative vorticity at two different times of an eddy shedding cycle (a), Project Nonlinear partial differential equations.




The normalized relative vorticity at two different times of an eddy shedding cycle (b), Project: Nonlinear partial differential equations.

José Miguel Urbano, U Coimbra, Principal Investigator, Project: Nonlinear partial differential equations.

been made against the antennas problem, but the study of this topic is not completed yet. For problems arising in superconductivity and the dynamics of sand piles, progress has also been made, although some clarifications are needed in order to bring this work to publication.

*Research metrics*
*Start date:* April 1, 2009 *End date:* March 31, 2013

The following research publications and presentations related to the project were accomplished by team members during the funded period:

- Papers in international journals or book chapters: 17
- Papers submitted or pending publication: 9
- Relevant presentation at international conferences and seminars: 25
- One PhD Thesis

In addition to these publications and presentations, project members organized two special scientific events, the *BCAM-CIM Workshop on Applied Mathematics in Bilbao, Spain* (July 2-4, 2009), and the *Minisymposium on Computational Atmospheric and Ocean Dynamics, ECCOMAS, Lisbon, 2010*.

## Project: Reaction-diffusion in porous media

*Principal Investigator:*
1. José Ferreira, U Coimbra
2. Gergina Pencheva, The University of Texas at Austin

*UT Austin Research Team*
3. Mary Fanett Wheeler, researcher
4. Mojdeh Delshad, researcher

*Portuguese Research Team*
5. Adérito Luís Martins Araújo, UCoimbra Faculty Researcher
6. Cidália Alves das Neves, UCoimbra Faculty Researcher
7. Ercília Cristina da Costa e Sousa, UCoimbra Faculty Researcher
8. Giuseppe Romanazzi, UCoimbra Faculty Researcher
9. Gonçalo Nuno Travassos Borges Alves da Pena, UCoimbra Faculty Researcher
10. Luís Miguel Dias Pinto, UCoimbra Faculty Researcher
11. Marc Baboulin, UCoimbra Faculty Researcher
12. Sílvia Alexandra Alves Barbeiro, UCoimbra Faculty Researcher
13. Fernando Manuel Lucas Carapau, University of Evora Researcher

*Research Team, Université Pierre et Marie Curie, Paris VI*
14. Vivette Girault

*The Project*
In recent decades, diffusion in porous media has attracted researchers from several disciplines, such as geosciences, environmental sciences, mechanics, biology, chemistry, petroleum engineering, biomedical engineering, physics and mathematics. Diffusion in porous media has applications to problems such as groundwater contamination, diffusion in polymers, and flow in oil reservoirs. The fundamental equation governing diffusion in porous media is the equation of mass conservation, which is of parabolic type. It is established assuming that the dispersive mass flux is given by Fick´s law where the dispersion tensor is assumed to be independent of the concentration and its gradient. It is well-known that this equation gives rise to an infinite speed of propagation. Small- and large-scale heterogeneities in porous matrix and/or fluid properties are the main sources of deviations of the so-called Fickian dispersion behavior. In order to overcome this deviation, a certain memory effect should be included in the flux modeling. The aim of this project is to introduce memory effects in the models for fluid flows in porous media characterized by small-scale and large-scale heterogeneities in several contexts.

The first stage of this research seeks to propose new mathematical models for non-Fickian flow in porous media. Researchers started by studying linear integro-differential equations that can be obtained combining the mass conservation law with the Maxwell Voight law for the mechanical behavior of the medium. In this way, memory effects were introduced in the models for fluid flows in porous media characterized by small-scale and large scale heterogeneities in several contexts. For the new models we gained some insight on the mathematical analysis of the mathematical problems and we developed discretization schemes and established stability and convergence.

To advance this research, the team organized the 2010 workshop "Diffusion in porous media," that took place in the University of Coimbra, in February; and a symposium with the theme, "New trends in diffusion phenomena," in the "European Conference on Computational Fluid Dynamics, ECCOMAS CFD 2010" June 14th-17th in Lisbon.

In 2009, Silvia Barbeiro and José Ferreira visited ICES at UT Austin November 15 to 26, to develop research work with the UT partners of the project. Mary Wheeler, with UT, visited the University of Coimbra in June 2010 to continue the research work with the members of the research team at U Coimbra.

The next step is to couple the diffusion equation studied in the first step with a reactive transport equation. After investigating this single phase flow and reactive transport, researchers propose to extend our results to the two phase immiscible reactive transport problem.The final goal is to consider multiphysics coupling systems and to perform numerical experiments for verifying theory and model some realistic engineering applications.

*Research metrics*

*Start date:* April 1, 2009 *End date:* March 31, 2012

The following projects outputs have resulted from this research:

- Organized meetings: 2
- Presentations: 12
- Seminars taught: 2
- Papers published or submitted for publishing: 10

## Project: SIMCARD, Patient-specific cardiovascular modeling & analysis

*Principal Investigators:*

1. Prof. Adélia Sequeira, IST
2. Prof. Thomas J. R. Hughes, UT Austin
3. Prof. Chandrajit Bajaj, UT Austin

*Portuguese Research Team*

4. Alberto Massimo Gambaruto, IST Faculty Researcher
5. Alexandra Bugalho de Moura, IST Faculty Researcher
6. Angel Rodríguez Rozas, IST PhD candidate
7. Carlos Alberto Mota Soares, IST Faculty Researcher
8. Diana Catarina da Fonseca Madeira Nunes, IST PhD candidate
9. Helder Carriço Rodrigues, IST Faculty Researcher
10. Jevgenija Pavlova, IST PhD candidate
11. João Gonçalo Silva Marques, IST PhD candidate
12. João Manuel Ribeiro da Silva Tavares, IST Faculty Researcher
13. João Orlando Marques Gameiro Folgado, IST Facutly Researcher
14. José Carlos Fernandes Pereira, IST Faculty Researcher
15. José Manuel da Silva Chaves Ribeiro Pereira, IST PhD candidate
16. Juan Antonio Acebron de Torres, IST Faculty Researcher
17. Marco Paulo Lages Parente, IST Faculty Researcher

18. Francisco Paulo Marques de Oliveira, UPorto PhD candidate
19. Ilda Marisa de Sá Reis, UPorto PhD candidate
20. Pedro Alexandre Lopes de Sousa Martins, UPorto PhD candidate
21. Zhen Ma, UPorto PhD canidate
22. João Paulo Vicente Janela,UTL Faculty Researcher
23. Jorge Rodolfo Gil Guedes Cabral Campos , Hospital de Santa Maria

### *The project*

SIMCARD is an interdisciplinary project that develops, analyzes, and simulates mathematical models of the cardiovascular system. Proposed by a mathematics professor, the project is technically qualified as a CoLab Advanced Computing research project; we present it here as a representation of the cooperation of these two CoLab programs.

According to the most recent statistics, cardiovascular diseases represent the major cause of death in developed countries. The important consequences of such diseases at the individual and social levels have a significant impact in the cost and overall status of healthcare. An increasing demand from the medical community for scientifically rigorous and quantitative investigations of cardiovascular diseases has given a major impulse to the development of mathematical models and numerical tools for the computer simulation of the human cardiovascular system, in both healthy and pathological states. However, the circulatory system is highly integrated and modeling its various functions is an incredibly challenging problem, which still requires many fundamental issues to be addressed.

This research aims to develop computational tools for the simulation of mathematical models of the human cardiovascular system. Cerebral vasculature pathologies and malformations, including aneurysms and stenoses, are studied from medical images. The work geared towards the study of realistic physiological processes and clinical application is striving for faster and more robust schemes as well as more physiologically accurate mathematical models. This involves virtual model reconstruction from medical images, uncertainty estimation of the virtual model definition, inter-patient characterization, validation of simulations with clinical data and feedback to physicians. Blood flow interacts mechanically with the vessel walls and gives rise to complex fluid-structure interaction problems that require appropriate algorithms to describe the energy transfer between the fluid and the structure. Accurate and efficient computations of the coupled problems are a difficult task due to large displacements and difference between time scales of the main blood flow and of the pulse propagation. We propose to extend the existent results and numerical codes, to couple non-Newtonian models for blood flow with complex models for the vessel wall, using non-standard defective boundary conditions to deal with real geometries reconstructed from medical images and data from measurements.

New computational methodologies and models will be developed to analyze the mechanical behavior of structures from medical image sequences, by adopting biomechanical principles. Namely, the segmentation, tracking and motion analysis of the heart from images, the estimation of the mechanical properties of its relevant tissues, by non-invasive techniques, and the development of 3D models of the heart, will contribute to simulate pathological cases of medical interest at reasonable computational costs. In the proposed work, there is an evident bottleneck of computational cost of the described simulations. This is seen especially in the numerical simulations of the non-Newtonian blood flow and the vessel structure dynamics, and their coupling. While some approaches to alleviate the computational costs, such as 0D (lumped parameter) or 1D reduced models can be used for simulating the vasculature far from the region of interest, the more accurate and complex the mathematical models, the more computationally intensive the simulation.

This is a multi-disciplinary collaborative project that involves large-scale computational simulations and requires a synergy of research efforts and knowledge of different fields. Dealing with specific problems of clinical interest, it will largely benefit from the longstanding national and international collaboration with bioengineers and medical doctors. This project will strongly contribute to strengthen the links between Portuguese researchers from several institutions (IST, FEUP, HSM – FML) with the research teams of UT Austin, whose expertise in the field is recognized worldwide.

### *Research metrics*

*Start date:* April 1, 2009 *End date:* March 31, 2012

The following set tasks have seen advancement in the past year's research:

- Medical imaging in vivo (MRI, MRA, CT)
- Medical image interpretation
- Numerical simulations of cerbral vasculature
- Uncertainty quanitification of vessel geometry variability
- Software development

Preliminary work has been carried out, and a variety of image interpretation techniques have been studied and their applications tests toward the two tasks of A*nalysis of the behavior of structures and estimation of their mechanical properties from images,* and *Experimental properties and reflexive activity of the tissues.* Results remain to be consolidated toward the task *micromechanical modeling and optimization of cardiovascular stents.* The following research publications and presentations related to the project were accomplished by team members during the reporting period.

- Books or special issue journals edited: 5
- Papers in international journals or book chapters: 20
- Papers in conference proceedings: 20
- Relevant presentation at international conferences and seminars: at least 24
- One PhD Thesis

In addition to these publications and presentations, project members organized ten special scientific events; and there are five related additional research projects related to the SIMCARD project.

## 2009 Call for Projects

The 2009 Mathematics call for research projects requested submissions in the following applications of mathematics:

- Advanced materials, including composites, micro- and nano-structures and biological structures, variational and numerical methods;
- Interfaces, front propagation and image processing, including variational models, numerical methods, applications to geophysics, environmental sciences, computational medicine, visualization, vision and image recognition;
- Applications to basic sciences including mathematical physics, computational chemistry and mathematical biology;
- Mathematical finance and stochastic network models, including risk modeling, utility based valuation, stochastic optimal control, stochastic networks, including analysis of complex large-scale networks, diffusion approximations, measure-valued processes and large deviations, as well as computational issues;
- Information and communication technology, including security information, sensor networks and human-computer interaction.

Submissions for high quality projects in non-applied areas of Mathematics were also encouraged. Another basic purpose of CoLab research projects is increased interaction between universities, and each research project application is required to implement a team-based approach that involves professors from at least two Portuguese universities, as well as one or more professors in the U.S. In addition to dispersing benefits of the research investment more widely across the nation of Portugal, and intrinsically improving inter-university relationships, this also helps increase the possibility of publications and similar diffusion of research results. Similarly, inclusion of graduate students as active research members helps further the overall CoLab goals. The following projects received funding from the FCT against this call for proposals.

- Applied mathematics: from dynamical systems to cryptography
- Mathematical modeling and endoscopic image processing
- Nonlinear partial differential equations
- Reaction-diffusion in porous media

In addition to these mathematics projects, the SIMCARD Project pursuing patient-specific cardio-vascular modeling, involved both researchers from both Colab's Advanced Computing and Mathematics groups, and is therefore represented in the annual report for both programs. Beyond meeting stated objectives, standard academic metrics for research success apply: publications in journals, book chapters, and books; and presentations in conferences, workshops, seminars, etc.

## New Projects Approved

*Stochastic Analysis and Numerical Approximations in Mathematical Finance (SANAF)* Principal Investigator: Cláudia Philippart, Instituto Superior Técnico (IST/UTL) in collaboration with Guoliang Wu (UT Austin) and Dmitry Kramkov (Carnegie Mellon University)

*Degenerate elliptic and parabolic equations and its applications to front propagation* Principal investigagor: Diogo Gomes, Instituto Superior Técnico (IST/UTL) in collaboration with Rafael de la Llave (UT Austin)

*Classical and Quantum Aspects of Geometry* Principal investigator: Lopes Cardoso, Instituto Superior Técnico (IST/UTL) in collaboration with David Ben-Zvi (UT Austin)

## Other Collaborations

*Faculty Exchange Program*

In order to build a successful UT-Austin Portugal Cooperative Program in Mathematics there needs to be a strong component of joint research at junior and senior levels. Accordingly, the CoLab program has provided a regular exchange of post-doc and junior faculty as well senior faculty to organize workshops to foster the development of common research interests and projects.

*Rocha, Cafarelli*

Eugénio Rocha is collaborating with Luis Caffarelli (CoLab@Austin Mathematics Director) in the study of the theoretical issues concerning subelliptic operators and (fractional) Laplacians evolving in Carnot groups (a subclass of nilpotent Lie groups).

*Barbeira, Wheeler*

Sílvia Barbeira is working with Mary F. Wheeler, from ICES, and her interests are in the field of numerical solution of partial differential systems applied to coupled geomechanics and reservoir flow models.

### *Videman, Figueirdo, Dawson, Arbic*

Juha Videman and Isabel Figueirdo from Portugal are pursuing research in collaboration with Clint Dawson, from ICES, and Brian Arbic, from UT Institute for Geographics, in partial differential equations in geophysical fluid dynamics.

### *Abreu, Gilbert*

Professors Luís Daniel Abreu (U Coimbra) and John Gilbert (UT Austin) have initiated a collaboration in the area of mathematical signal analysis. Their focus is "Harmonic analysis on contractions of the phase plane," in the mathematics section of the UT Austin | Portugal program. For this purpose, Professor Abreu visited Austin in July 2009 and January 2010. The two researchers apply the representation theory of the contractions of the Heisenberg group to the construction of frames. They use methods from complex and harmonic analysis. Their theoretical results may lead to new implementable algorithms for the analysis and synthesis of signals supported on compact sets. The outcome of this research is expected to promote a transference of knowledge between the mathematics and communications engineering communities involved in the UT Austin | Portugal program.

### *Salgueiro, Luecke*

Assistant Professor Antonio Salguiro (U Coimbra) visited Professor John Luecke (UT Austin) from August 13 to 24, 2010to start a collaboration in the area of geometric topology. They studied the cyclic coverings of knots and links using the JSJ decomposition of 3-manifolds and methods from hyperbolic geometry, Seifert fibred space theory and graph theory. In particular they expect to understand if all coverings of different degrees of a given nontrivial link are nonhomeomorphic.

### *Figueiredo, Stadler, Ghattas, Engquist, Tsai*

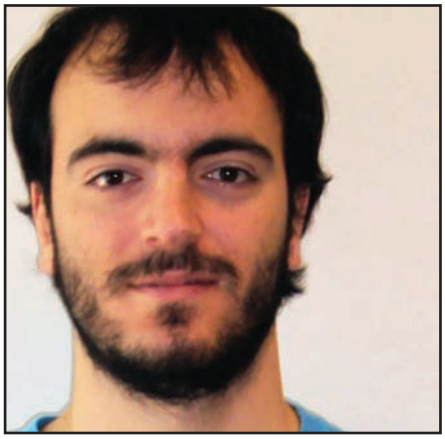
July 01, 2009 to March 31, 2010, the U Coimbra research team for the endoscopy project developed some effective research collaboration with the following project members of UT Austin: Georg Stadler, Omar Ghattas, Bjorn Engquist and Richard Tsai. In particular, Isabel Figueiredo visited ICES, UT Austin, from August 30 to October 2, 2009, and also from March 1 to May 7, 2010; she has returned this fall, having arrived August 27, and plans to continue her collaborations in residence at the Institute for Computational Engineering & Science (ICES), until October 2, 2010.

## Post Doctoral Opportunities: Doctoral Fellows

In order to pursue the internationalization of Portuguese universities it has been considered essential to develop a post-doc and junior faculty exchange program. Such a program would attract talented recent graduates and junior faculty from UT-Austin to Portugal as well as send to Austin recent Portuguese graduates and junior faculty. In Portugal and at UT-Austin post-doctoral and junior faculty positions would be funded by the UT-Austin Portugal Program and post-docs would be expected to have a reduced teaching load. Furthermore, in order to foster joint research enterprise at the senior level yearly workshops will be organized alternating between Austin, Coimbra and Lisbon. Current Doctoral Fellows of the program include:

- Maria Teresa Perez
- Farid Bozorgnia
- Stephania Patrizi
- Gabriele Terrone

Stephania Patrizi, Doctoral Fellow



Diego Farias

# EDUCATION

## PhD Program

The Lisbon-University of Texas at Austin PhD Program in Mathematics (LUTAMath) is a dual PhD program between the Mathematics Departments of the three Lisbon public universities (Instituto Superior Técnico, Universidade de Lisboa and Universidade Nova de Lisboa) partnered with the University of Texas at Austin.

This internationally attractive graduate program is organized along the following guidelines: Students enrolled must satisfy the requirements of all of the participating universities. Therefore, upon completion of these academic requirements, the student will be allowed to submit his thesis both at the participating Portuguese universities and at UT Austin and the student will be able to obtain a degree in mathematics from both participating institutions.

There is a long history of scientific interaction between the Department of Mathematics at UT Austin and Portuguese universities namely in the areas of applied mathematics and partial differential equations. Furthermore, both UT Austin and the involved Portuguese universities have strong and complimentary groups in geometry and topology providing the framework for strong intellectual cooperation to promote high quality scientific collaborations and research. In the near-term, collaborations will also include other areas such as mathematical finance and algebra.

Levon Nurbekian

Portuguese and UT Austin students should be involved in these cooperative research activities as soon as possible so that they can obtain the most benefit from these bi-national collaborations. Research activity resulting from this cooperative program should be monitored by established research centers at the participating universities and which employ the involved researchers including the following key Portuguese faculty and institutions: Rui Loja Fernandes and Diogo Gomes (IST); Luisa Mascarenhas and Luís Trabucho (FCT-UNL); José Francisco Rodrigues and Jean-Claude Zambrini (FC-UL).

## 2010 Call for Doctoral Scholarships

In the context of the UT Austin|Portugal Program, the FCT (Foundation for Science and Technology) opened a call for: Mathematics PhD Scholarships, taking place in Portugal and at University of Texas, at Austin in the following areas:

- Algebra and Number Theory
- Applied and Numerical Analysis
- Analysis and Partial Differential Equations
- Geometry and Topology
- Optimization
- Stochastic Processes and Mathematical Finance
- Dynamical Systems

Verónica Quítalo

The scholarship is only given to those candidates that are able to demonstrate that they were accepted in one of the PhD Programs by a Portuguese University involved with the UT Austin|Portugal Program for the different areas.

Scholarships were granted under the conditions stated by the FCT on the Scientific Fellow's Regulation (Law n. 40/2004, of August 18th) and on the Regulations for Advanced Training and Qualification of Human Resources of the FCT (http://alfa.fct.mctes.pt/apoios/bolsas/regulamento.phtml.en).

The scholarships are funded by the QREN Portugal 2007-2013 Operational Program Human Potential and by funds from the Ministry of Science, Technology and Higher Education. Application to these scholarships is open to all candidates that comply with the requirements established on Article 17 of the Regulation on Advanced Training and Qualification of Human Resources of the Foundation for Science and Technology. The candidates to PhD scholarships who have held the same type of scholarship under other FCT Programs will be limited to a maximum number of years of support. The number of years of support will be a sum of the previous and present scholarship. The evaluation of candidates will be based on the merit and motivation of the applicants. The evaluation panel will review the applications, analyze the candidate's merits and motivations, and produce an ordered list of the accepted applicants. Students approved through this process include:

- Diego Farias
- Levon Nurbekian
- Verónica Quítalo
- Rafayel Teymurazyan
- Hassan Najafi Alishah

Rafayel Teymurazyan

Hassan Najafi Alishah

# EVENTS

## Colloquium: Bjorn Engquist, UCoimbra

*Computational Multiscale Modeling: Crypt dynamics with budding and fission*

**Nov 4, 2009** It is generally accepted that colorectal cancer is initiated in the small pits, called crypts, that line the colon. This presentation examines progress in simulating the abnormal geometry of aberrant colonic crypts, by using reaction-diffusion equations, which model the dynamics of proliferative and apoptotic colonic cells.

## Workshop: Classical and Random Dynamics in Mathematical Physics

**March 30 – April 3, 2010, The University of Texas at Austin.** The UT Math CoLab group provided a four-day workshop on classical and random dynamics in mathematical physics, consisting of a series of 45-minute plenary session talks. Abstracts included:

**Recurrence times toward mixing rates and vice-versa** *(José Ferreira Alves, Universidade de Porto)* One of the most efficient tools for studying the mixing rates of certain classes of dynamical systems is through Young towers: if a given system admits an inducing scheme whose tail of recurrence times decays at a given speed, then that system admits a physical measure with mixing rate of the same order. This talk considered the inverse problem: assume that a given dynamical system has a physical measure with a certain mixing rate; under which conditions does that measure come from an inducing scheme with the tail of recurrence times decaying at the same speed? Optimal results for the polynomial case were presented. The exponential case raises interesting questions on the regularity of the observables.

**On the Boltzmann limit for a Fermi gas in a random medium with dynamical Hartree-Fock interactions** *(Thomas Chen, The University of Texas at Austin).* This session addressed the dynamics of a Fermi gas in a weakly disordered random medium. First, some joint results reached with I. Sasaki (Shinshu University) were presented on the Boltzmann limit for the thermal momentum distribution function, and on the persistence of quasifreeness, for the case of a free Fermi gas in a random medium. Subsequently, joint results with I. Rodnianski (Princeton University) were presented on the derivation of the Boltzmann limit for a Fermi gas in a random medium with nonlinear self-interactions modeled in dynamical Hartree-Fock theory.

**Planar fronts in bistable coupled map lattices** *(Ricardo Coutinho, Universidade Técnica de Lisboa).* Planar fronts in multidimensional coupled map lattices can be studied by reduction to an one-dimensional extended dynamical system that generalises one-dimensional coupled map lattices. This methodology was fully investigated and developed. Continuity of fronts velocity with the coupling strength and with the propagation direction was proven. Examples were provided and illustrated by some numerical pictures.

**Invariant objects in coupled map lattices** *(Rafael de la Llave, The University of Texas at Austin).* Infinite dimensional systems were considered, which consist of copies of a finite dimensional system at each point in the lattice coupled by interactions which decrease fast enough. These objects have appeared in applications under the name of *coupled map lattices, oscillator networks,* and in discretizations of PDE's. Detail hyperbolic systems were considered, with their invariant manifolds. In relation to Hamiltonian systems, whiskered invariant tori and their invariant manifolds were discussed. The method allows consideration of the persistence of tori with finitely many or infinitely many frequencies. This work was developed jointly with E. Fontich, P. Martin, Y. Sire (previous work with M. Jiang).

**Integrable billiards, Poncelet-Darboux grids and Kowalevski top** *(Vladimir Dragovic, Universidade de Lisboa).* A progress in a thirty years old programme of Griffiths and Harris of understanding of higher-dimensional analogues of Poncelet porisms and synthetic approach to higher genera addition theorems was presented. A set $T$ of lines tangent to $d$-$1$ quadrics from a given confocal family in a $d$-dimensional space, as equipped with an algebraic operation; applied to further develop well-known results of Donagi, Reid and Knorrer. Having derived a fundamental property of $T$: any two lines from $T$ can be obtained from each other by at most $d$-$1$ billiard reflections at some quadrics of the confocal family. The interrelations among billiard dynamics, linear subspaces of intersections of quadrics and hyperelliptic Jacobians enabled us to obtain higher-dimensional and higher-genera generalizations of several classical genus $1$ results. Among several applications, a new view on the Kowalevski top and Kowalevski integration procedure is presented. It is based on a classical notion of Darboux coordinates, a modern concept of $n$-valued Buchstaber-Novikov groups and a new notion of discriminant separability. An unexpected relationship with the Great Poncelet Theorem for a triangle was illustrated.

**Extensions of the *Kac N*-particle model to multi linear interactions** *(Irene Gamba, The University of Texas at Austin).* This session examined extensions *Kac N*-particle model of pair interactions to an *N*-particle model which includes multi-particle interactions in order to study the evolution of the corresponding probability density solution. Under the assumption of temporal invariance under scaling transformations of the phase space and contractive properties, we obtain a full description of existence, uniqueness and long time behavior from its spectral properties. This model can also be seen as an extension of the Boltzmann dynamics of Maxwell type for conservative or dissipative interactions and the formation of power tails for long time self similar behavior under very general conditions for the initial energy. Focus also included new examples of multi-agent dynamics and information percolation and some numerical simulations. This work is the result of collaboration with A. Bobylev, C. Cercignani. The Numerical simulations, the result of collaboration with Harsha Tharkabhushanam and the recent studies for information dynamics models with Ravi Srinivasan.

**Non Convex Aubry-Mather Measures** *(Diogo Gomes, Universidade Técnica de Lisboa).* This discussion presented the adjoint method introduced by Evans to construct analogs to the Aubry-Mather measures for non-convex Hamiltonians. In particular, these prove the existence of Aubry-Mather measures for a class of strictly quasiconvex Hamiltonians.

**A rigorous approach to the non-Abelian Chern-Simons path integral** *(Atle Hahn, Universidade de Lisboa)*. The study of the heuristic Chern-Simons path integral by E. Witten inspired (at least) two general approaches to quantum topology. Firstly, the perturbative approach based on the *CS* path integral in the Lorentz gauge and, secondly, the "quantum group approach" by Reshetikhin/Turaev. While for the first approach the relation to the *CS* path integral is obvious for the second approach it is not. In particular, it is not clear if/how one can derive the relevant *R*-matrices or quantum *6j*-symbols directly from the *CS* path integral. This discussion summarizes the results of a recent preprint, to sketch a strategy that might lead to a clarification of this issue in the special case where the base manifold is of product form. This strategy is based on the "torus gauge fixing" procedure introduced by M. Blau and G. Thompson for the study of the partition function of *CS* models. The presentation show that the formulas of Blau & Thompson can be generalized to Wilson lines and that at least for the simplest types of links the evaluation of the expectation values of these Wilson lines leads to the same state sum expressions in terms of which Turaev's shadow invariant is defined. Finally, the presentation showed how, with the use methods from Stochastic Analysis or, alternatively, a suitable discretization approach, one can obtain a rigorous realization of the path integral expressions appearing in this treatment.

**Homoclinic Tangle Dynamics in a Vortex-Bubble** *(Jay Mireles James, Rutgers University)*. This session presented a three dimensional, quadratic, volume preserving map, which is a normal form for quadratic diffeomorphisms with quadratic inverse. The map can also serve as a toy model for a certain type of vortex dynamics which arises in fluid and plasma physics. Also discussed a quasi-numerical numerical scheme, based on the Parameterization Method, for accurately computing the one and two dimensional stable and unstable manifolds of the maps fixed points. A study of the embedding of the stable and unstable manifolds provided insights into the chaotic motions in the vortex.

**Shadowing orbits for dissipative PDEs** *(Hans Koch, The University of Texas at Austin)*. This session presented a computer-assisted technique for constructing and analyzing orbits of dissipative evolution equations. As a case study, the methods were applied to the Kuramoto-Sivashinski equation. In particular, a partial description of the bifurcation diagram for stationary solution was shown, which involves 23 bifurcations and 44 branches; and further illustrated how more general orbits may be obtained by solving the Duhamel equation for small time intervals, and then using shadowing techniques (covering relations). Estimates were described on the flow, its derivative, Poincaré maps, and a proof for the existence of a hyperbolic periodic orbit. This is a joint work with Gianni Arioli (Politecnico di Milano).

**Equivariant Landau-Lifshitz equation of degree two** *(Kenji Nakanishi, Kyoto University)*. This presentation shared joint work that was developed with Stephen Gustafson and Tai-Peng Tsai on the global dynamics of the Landau-Lifshitz equation around the ground states under the equivariant symmetry. Having previously proved that in the degree higher than two, every solution with energy close to the ground states converges to a ground state of a fixed scaling at time infinity, whereas in the degree two, the family of the ground states is still asymptotically stable but the scaling parameter can blow up or oscillate at time infinity; the latter result, however, needed additional restrictions for which the dispersion was absent (i.e. the heat flow), and the map modulo the equivariant rotation was confined in a great circle. This work illustrates how those restrictions for the asymptotic stability might be removed.

***Stochastic partial differential equations: Regularity of the probability law of the solution*** *(David Nualart, University of Kansas)*. Recent results were shared on the regularity of the density of the solution of a general class of stochastic differential equations driven by a Gaussian white noise with an homogeneous spacial covariance. To show that the density of the solution is infinitely differentiable, the techniques of Malliavin calculus were applied, requiring the diffusion coefficient to satisfy some non degeneracy conditions. Discussions also covered the relation of this problem with the existence of negative moments for solutions to linear stochastic partial differential equations with random coefficients. A recent approach to this question using a stochastic version of Feynman-Kac formula was also presented.

**Yang-Mills in 2 dimensions for *U(N)* and its large-*N* limit (***Ambar N. Sengupta, Louisiana State University)*. This presentation described quantum Yang-Mills theory on the plane with the gauge group *U(N)*, and the limiting behavior of this theory as *N* goes to inifinity.

**Stochastic wave equation model for heat-flow in non-equilibrium statistical mechanics** *(Lawrence E. Thomas, University of Virginia)*. In consideration of a one-dimensional non-linear stochastic wave equation system modeling heat flow between thermal reservoirs at different temperatures, this session provided a brief review of the problem of solving these equations in Sobolev spaces of low regularity. The system with ultraviolet cutoffs has, for each cutoff, a unique invariant measure exhibiting steady-state heat flow. Estimates were provided on the field covariances with respect to the invariant measures which are uniform in the cutoffs.

**Transitivity of non-compact extensions of hyperbolic systems** *(Andrew Török, University of Houston)*. In consideration of the restriction to a hyperbolic basic set of a smooth diffeomorphism, this session focused on the transitivity of Hölder skew-extensions with fiber a non-compact connected Lie group. In the case of compact fibers, the transitive extensions contain an open and dense set. For the non-compact case, it was conjectured that this is still true within the set of extensions that avoid the obvious obstructions to transitivity. Results that support this conjecture were discussed. For $r > 0$, it was shown that in the class of $C^r$-cocycles with fiber the special Euclidean group *SE(n)*, those that are transitive form a residual set (countable intersection of open dense sets). This result is new for $n \geq 3$ odd. More generally, the presentation considered Euclidean-type groups $G \propto \mathbf{R}^n$, where *G* is a compact connected Lie group acting linearly on $\mathbf{R}^n$. When Fix $G = \{0\}$, it is again the case that the transitive cocycles are residual. When Fix $G \neq \{0\}$, the same result holds on the subset of cocycles that avoid an obvious and explicit obstruction to transitivity. Proof was shown that such genericity results for a class of nilpotent groups. This is a joint work with with Ian Melbourne and Viorel Nitica.

**Strong stochastic stability for non-uniformly expanding maps** (*Helder Vilarinho, Universidade da Beira Interior)*. This discussion addressed the strong stochastic stability of a broad

class of discrete-time dynamical systems—non-uniformly expanding maps-when some random noise is introduced in the deterministic dynamics. A weaker form of stochastic stability for this systems was established by J. F. Alves and V. Arajo (2003) in the sense of convergence of the physical measure to the SRB probability measure in the weak* topology. A strategy was presented to improve this result in order to obtain the strong stochastic stability, i.e., the convergence of the density of the physical measure to the density of the SRB probability measure in the L1-norm, and in a more general framework of random perturbations. A result was illustrated for two examples of non-uniformly expanding maps: the first as related to an open class of local diffeomorphisms introduced by J. F. Alves, C. Bonatti and M. Viana (2000) and the second to Viana maps—a higher dimensional example with critical set introduced by M. Viana (1997). This is a joint work with J. F. Alves.

**Stochastic completeness of graphs** *(Radosław Wojciechowski, Universidade de Lisboa).* This presentation introduced the heat kernel on graphs and gave geometric conditions which imply the stochastic completeness or incompleteness of the underlying diffusion process. Furthermore, connections to the spectrum of the discrete Laplacian were considered. The proofs rely on studying the stability of solutions of difference equations.

**Stochastic reversible deformation of dynamical systems** *(Jean-Claude Zambrini, Universidade de Lisboa).* This session described a program of symmetrization in time of Stochastic Analysis. Its main purpose being to deform stochastically the classical approaches to the theory of elementary dynamical systems, but it may be of interest more generally when random modeling of reversible phenomena is necessary.

## Colloquium: Mary Wheeler, U Coimbra

***June 8, 2010*** A fundamental difficulty in understanding and predicting large-scale fluid movements in porous media is that these movements depend upon phenomena occuring on small scales in space and/or time. The differences in scale can be staggering. Aquifers and reservoirs extend for thousands of meters, while their transport properties can vary across centimeters, reflecting the depositional and diagenetic processes that formed the rocks. In turn, transport properties depend on the distribution, correlation and connectivity of micron sized geometric features such as pore throats, and on molecular chemical reactions. Seepage and even pumped velocities can be extremely small compared to the rates of phase changes and chemical reactions. The coupling of flow simulation with mechanical deformations is also important in addressing the response of reservoirs located in structurally weak geologic formations.

The pesentation focused on the mortar mixed finite element method (MMFE) that was first introduced by Arbogast, Cowsar, Wheeler, and Yotov for single phase flow and later extended to multiphase flow by Lu, Pesyznska, Wheeler, and Yotov for multiphase flow. The MMFE method is quite general in that it allows for non-matching interfaces and the coupling of different physical processes in a single simulation. This is achieved by decomposing the physical domain into a series of subdomains (blocks) and using independently constructed numerical grids and possibly different discretization techniques in each block. Physically meaningful matching conditions are imposed on block interfaces in a numerically stable and accurate way using mortar finite element spaces. The mortar approach can be viewed as a subgrid or two scale approach. Moreover, the use of mortars allows one to couple MFE and discontinuous Galerkin approximations in adjacent subdomains. Discussions also explored the use of mortars for poroelastic problems. This presentation discussed theoretical *a priori* and *a posteriori* results and computational results were be presented.

## Summer School and Workshop: Imaging Sciences & Medical Applications

*by Isabel M. Narra Figueiredo, UCoimbra, Organizer*

***June 15-23, 2010*** The Summer School and Workshop on Imaging Sciences and Medical Applications was an initiative of the UTAustin | Portugal Program, for Mathematics, in partnership with CIM (Center for International Mathematics). It took place at the Department of Mathematics at the University of Coimbra Faculty of Sciences and Technology, in Coimbra, Portugal, on June 15-23, 2010. This event had also the scientific support of CMUC (Centre for Mathematics, University of Coimbra), and two Portuguese medical associations, the Brain Imaging Network and the Society of Digestive Endoscopy.

The choice of the topic (and, a posteriori, its location) was chosen to support a research project (reference UTAustin/MAT/0009/2008), in the framework of the UTAustin | Portugal Program (for Mathematics), and one of the project main subjects is precisely image processing of medical images, more exactly, endoscopic images in gastroenterology. Moreover, this Summer School and Workshop on Imaging Sciences and Medical Applications was also, in some sense, a natural consequence (and a continuation) of the Workshop on Mathematical Aspects of Imaging, Modeling and Visualization in Multiscale Biology, in which we were directly and strongly involved, and that took place at the ICES (Institute for Computational Engineering and Sciences), of the University of Texas, at Austin, USA, from March 31st to April 4th 2009.

The main goal of the Summer School and Workshop on Imaging Sciences and Medical Applications was to promote new collaborations, to exchange and share new ideas and scientific results, and simultaneously, to give an opportunity to PhD students and young researchers for improving their scientific knowledge inthe complex area of imaging sciences, which has strong interdisciplinary features.

The Summer School featured five excellent short courses, each one with the duration of five hours, presented by experts in imaging sciences. In the Workshop there were nine plenary lectures, with a predominance of Portuguese guest speakers. The Workshop also included four sessions of contributed talks and one poster session, which gave the possibility to young re-

searchers to report their ongoing work and results. A broad audience of sixty participants attended this event, which included mathematicians, electrical and computer engineers, mechanical engineers, biomedical engineers, geographical engineers, computer scientists and a neuroscientist. This premier event featured speakers who strongly contributed to a top level scientific atmosphere, promoting and encouraging interactions and collaborative research among all the participants. Abstracts of these sessions follow.

### *Summer School courses (June 15-19)*

**Highly accurate image restoration and matching**, *Andres Almansa (Telecom Paris Tech, France)*. Image sampling (hexagonal and irregular) restoration (of bandlimited blurred and noisy images from those samples), and reliable sub-pixel block-matching were addressed. Techniques discussed included harmonic and non-harmonic analysis, TV minimization, and a particular kind of statistical hypothesis testing called "a contrario" methods.

**Variational models in image inpainting**, *Selim Esedoglu (University of Michigan, USA)*. Image inpainting is the process of automatically filling in damaged regions in digitized pictures with information gleaned from surrounding, undamaged areas. It has been a very active area of mathematical research in image processing. This presentation described some of the variational and partial differential equations based models proposed for this application, and discuss efficient numerical methods for their solution. Topics included some of the more recent non-local models.

**Image segmentation**, *Sung Ha Kang (Georgia Inst. of Technology, Atlanta, USA)*. Deterministic approaches for image segmentation and active contours will be presented, using variational formulations, non-linear partial differential equations and level sets. The segmentation problem in image processing and computer vision, aims to find boundaries of objects in images or to partition a given image into its constituent objects. One of the main applications of segmentation is in the medical field. Most relevant edge-based and region-based models were described in detail, together with their extensions to color, texture, or medical images. Numerical algorithms were presented in details.

**Image reconstruction in tomography**, *Alfred K. Louis (Saarland University, Germany)*. In imaging technologies, both in medicine and in non-destructive testing, the task is to reconstruct the desired information from measured data. As a first step, the development of mathematical models needs to be addressed. The reconstruction then is the inverse problem.This discussion explored several imaging technologies including x-ray CT, MRI, and ultrasound CT. As a case model, the Radon transform was presented as mathematical model for 2D CT. Inversion formulae were derived and principles for constructing fast algorithms were analyzed. The questions of uniqueness and resolution for a given data set were reviewed. Finally the presentation included the data analysis part into the reconstruction in order to determine features of the image in just one step. Optimal filters were discussed, with a study of the behavior for real data sets, as well as the extensions of the methods to 3D X-ray CT and ultrasound CT.

**Flexible algorithms for image registration**, *Jan Modersitzki (McMaster University, Canada)*. A generic task in modern image processing is image registration, needed for integration and/or comparison of data obtained from different images. Particularly in a medical environment, there is a huge demand for comparing pre- and post-intervention images, integrating modalities like anatomy (obtained, e.g., from computer tomography) and functionality (obtained, e.g., from positron emission tomography), motion correction and/or reconstruction of two-dimensional projections from a three-dimensional volume (applies to all tomography techniques and histology). The problem is easily stated: given two images (a reference and a template image), and a transformation, such that the transformed image is similar to the reference image.

This course presented a general and unified approach to image registration. The course covered central problems arising in typical applications, including both theoretical as well as practical components. Implementation issues were discussed on the basis of the FAIR software, see http://www.cas.mcmaster.ca/fair/index.shtml for details.

### *Summer Workshop Plenary Sessions*

**Interest point detection and matching for 3D reconstruction in medical endoscopy**, *João Pedro Barreto (University of Coimbra, Portugal)*

**Unmixing of positive sources in hyperspectral imaging**, *José Bioucas (Instituto Superior Técnico, Lisbon, Portugal)*

**From models of brain function to clinical applications: new challenges in neuroimaging**, *Miguel Castelo-Branco (University of Coimbra, Portugal)*

**CAGE: Computer assisted gastroenterology examination**, *Miguel Coimbra (University of Porto, Portugal)*

**A combinatorial point of view for non-linear evolutions**, *Jérôme Darbon (Ecole Normale Superieure de Cachan, France)*

**Removing non-additive noise using variable splitting and augmented lagrangian optimi-zation**, *Mário Figueiredo (Instituto Superior Técnico, Lisbon, Portugal)*

**Spatially adapted regularization in total variation based image restoration**, *Michael Hintermüller (Humboldt-University of Berlin, Germany)*

**New trends in photogrammetry and computer vision applied to 3D city modeling and cultural heritage**, *Marc Pierrot-Deseilligny (Laboratoire MATIS, IGN, France)*

**Tracking moving objects in image sequences,** *João Manuel R. S. Tavares (University of Porto, Portugal)*

## Ciência 2010

***July 4-7, 2010, Lisboa*** CoLab mathematics students presented scientific posters related to their PhD theses and the work they are developing in the CoLab program. The posters were on display for the length of the conference. One conference session was organized to provide students an opportunity to answer questions on their work.

Gabriele Terrone, a UTAustin|Portugal Mathematics CoLab Postdoctoral Fellow (IST), presented a session titled, *Limiting relaxed controls and homogenization of moving interfaces.*

# PENDING EVENTS

## Post-doctoral Academy in Mathematics

**September 23-24, 2010, Universidade Nova de Lisboa.** CoLab's 2010 Post-doctoral Academy in Mathematics is to address a number of indepth subjects, as follows.

**Long-time nonlinear dynamics of waves and clusters** *(Robert Pego, CMU).* Nonlinear dynamics in infinite-dimensional systems exhibit a rich set of phenomena. These lectures will focus on two of these. First: the stability and scattering questions for solitary waves in fluids and particle lattices. These particle-like nonlinear waves appear robust in these systems, but variational methods fail to work. Discussion will address how scattering behavior can be used to produce 'dissipation' estimates that allow one to extend stability results for integrable models like the KdV and Toda lattice equations. Second: the kinetic models of coagulation and clustering. Here the study of dynamic scaling limits provides close analogies connections with classical probability theory. The notion of the scaling attractor and the linearization of dynamics on it achieved by Bertoin's Levy-Khintchine representation of eternal solutions was described. The series of lectures included:

*1. Solitary waves in fluids and particle lattices.* Geometric stability theory in Hamiltonian systems of particles: symplectic tubular coordinates, Howland-type Floquet theory, Backland transform for the Toda lattice. Mizumachi's results on stability in the energy space.

*2. Solitary water waves.* KdV limit and spectral stability. Neumann-Dirichlet and Riemann mappings, Gohberg-Sigal-Rouche theorem.

*3. Clustering models, Smoluchowski's coagulation equation.* Random shock clustering; Burgers turbulence and the Carraro-Duchon-Bertoin theorem. Necessary and suficient criteria for approach to self-similar form.

*4. Scaling dynamics in general for solvable coagulation equations.* The scaling attractor and its measure representation. Conjugacy with dilational dynamics. Signatures of chaos. Analogy to stable laws of probability and infinite divisibility.

**Financial Markets: Black-Scholes and Beyond** *(Gordan Zitkovic, UT Austin).* The (by now) classical mathematical theory of continuous-time financial markets, based on the notion of "no arbitrage," provides a simple framework for study and analysis of many phenomena observable in financial markets. However elegant, this theory has severe limitations and a rather restricted domain of applicability. These lectures will provide a quick overview of some of its main features and present solutions to several problems outside its scope:

*1. A Crash-Course In Stochastic Analysis:* random walks and Brownian motion; continuous-time martingales; quadratic variation; stochastic integration; representation of martingales; Girsanov's theorem.

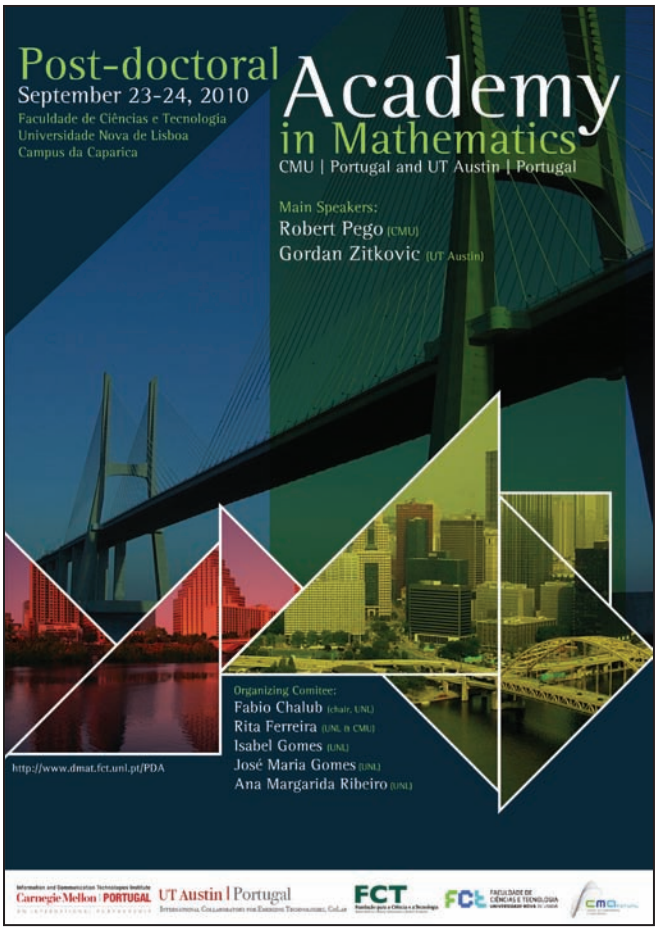
*2. Samuelson's (Black-Scholes-Merton) Model And Basic Notions Of Mathematical Finance:* geometric Brownian motion; portfolios and trading; no arbitrage; pricing by replication and the formula of Black and Scholes; martingale measures; complete vs. incomplete markets.

*3. Risk Aversion and Utility Maximization:* St. Petersburg paradox; utility functions and risk aversion; Merton's problem; variants; Hamilton-Jacobi-Bellman equations vs. the convex-analytic approach.

*4. Pricing Derivatives Beyond Black-and-Scholes:* the notion of a competitive equilibrium; utility-based and indifference pricing.

Graduate researchers in the CMU|Portugal and UT Austin | Portugal programs are also to make presentations:

- Filippo Cagnetti *(Instituto Superior Técnico, Portugal)*
- Mohammad El Smaily *(Pacific Institute for the Mathematical Sciences and at The University of British Columbia)*
- Rita Ferreira *(Carnegie Mellon University and Universidade Nova de Lisboa)*
- Carolin Kreisbeck *(Carnegie Mellon University)*
- Rafayel Teymurazyan *(Universidade de Lisboa)*




## Summer School and Workshop: Optimization in Machine Learning

**May 31 - June 7, 2011. Summer Course and Workshop, The University of Texas at Austin Austin, Texas, USA**. In addition to support from UT Austin|Portugal CoLab, this event is also part of the programs of the Portuguese Operations Research Society (APDIO) and the Portuguese International Center forMathematics (CIM).

**The Summer Course on Optimization in Machine Learning** (May 31 - June 4, 2011) will consist of two 10-hour modules

given by Katya Scheinberg (Lehigh University) and Nati Srebro (Toyota Technological Institute at Chicago). This Summer Course introduces a range of machine learning models and optimization tools that are used to apply these models in practice. For the students with some Machine Learning background the course will introduce what lies behind the optimization tools often used as a black box as well as an understanding of the trade-offs of numerical accuracy and theoretical and empirical complexity. For the students with some Optimization background this course will introduce a variety of applications arising in Machine Learning and Statistics as well as novel optimization methods targeting these applications. The models we will cover include: support vector machines, sparse regression, sparse PCA, collaborative filtering, dimensionality reduction. The optimization methods will include interior point, active set, stochastic gradient, coordinate descent, cutting planes method.

**The Workshop on Optimization in Machine Learning** (June 6-7, 2011) will consist of 60-minute plenary talks and a number of talks and poster presentations. Plenary speakers already confirmed for the workshop include:

- Kristin P. Bennett (Rensselaer Polytechnic Institute)
- Inderjit S. Dhillon (University of Texas at Austin)
- Lieven Vandenberghe (University of California, Los Angeles).

Organizers of this event are:

- Omar Ghattas (University of Texas at Austin)
- Katya Scheinberg (Columbia University)
- Luis Nunes Vicente (University of Coimbra).

### *Contact and deadlines*

The deadline for the course registration is March 31, 2011. For course and workshop registration please send email to oml2011@math.utexas.edu.

# THE MATHEMATICS COLAB GROUP

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