Activity Report 2011

Project-Team MACS

Modeling, analysis and control in computational structural dynamics

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Keywords: Scientific Computation, Finite Elements, Data Assimilation, Inverse Problem, Virtual Physiology, Fluid-Structure Interaction

1. Members

Research Scientists

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Daniele Trimarchi

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Nicolae Cîndea [till September]
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2. Overall Objectives

2.1. Introduction

Numerical simulation has become a widespread tool in engineering. This fact is particularly noteworthy in the field of solid and structural mechanics which has given birth to finite element methods. In industrial design processes, experimenting and simulation go hand in hand, but the balance is increasingly shifted towards simulation, resulting into reduced costs and time to market.

In this general context, the objectives of the Macs project are to address new challenges arising from:

- the need to develop numerical procedures which are *reliable* and well-adapted to *industrial applications*;

- the emergence of *active mechanics* (e.g. control and optimisation) enabling the design of thinner and lighter (hence cheaper) structures, for which innovative modeling and discretization approaches are required.

These research directions benefit from a strong scientific environment and background at INRIA in the fields of numerical analysis and scientific computing (with a well-established record in structural mechanics), as well as in automatic control.

We also emphasize that – in the past five years – we have increasingly investigated specific topics pertaining to biomechanical modeling.

2.2. Highlights

- First clinical validations on predictivity of cardiac biomechanical modeling for resynchronization therapy (CRT) planning, see [5];
- First results on data assimilation with actual medical images in collaboration with Hôpital Henri Mondor, see [1];

These highlights have been demonstrated in the News Focus entitled "La météo du cœur" shown in the Soir3 TV news on November 16th.

3. Scientific Foundations

3.1. Formulation and analysis of effective and reliable shell elements

Thin structures (beams, plates, shells...) are widely considered in engineering applications. However, most experts agree that the corresponding discretization procedures (finite elements) are not yet sufficiently reliable, in particular as regards shell structures. A major cause of these difficulties lies in the numerical locking phenomena that arise in such formulations [14].

The expertise of the team in this area is internationally well-recognized, both in the mathematical and engineering communities. In particular, we have strongly contributed in analysing – and better explaining – the complex locking phenomena that arise in shell formulations [14]. In addition, we have proposed the first (and only to date) shell finite element procedure that circumvents locking [21]. However, the specific treatment applied to avoid locking in this procedure make it unable to correctly represent membrane-dominated behaviors of structures (namely, when locking is not to be expected). In fact, a "perfect shell element" – namely, with the desired reliability properties mathematically substantiated in a general framework – is still to be discovered, whereas numerous teams work on this issue throughout the world.

Another important (and related) issue that is considered in the team pertains to the design and analysis of numerical procedures that are adapted to industrial applications, i.e. that fulfill some actual industrial specifications. In particular, in the past we have achieved the first mathematical analysis of "general shell elements" – which are based on 3D variational formulations instead of shell models – these elements being among the most widely used and most effective shell elements in engineering practice.

3.2. Stability and control of structures

Stability of structures is – of course – a major concern for designers, in particular to ensure that a structure will not undergo poorly damped (or even unbounded) vibrations. In order to obtain improved stability properties – or to reach nominal specifications with a thinner a lighter design – a control device (whether active, semi-active, or passive) may be used.

The research performed in the team in this area – other than some prospective work on robust control – has been so far primarily focused on the stability of structures interacting with fluid flows. This problem has important applications e.g. in aeronautics (flutter of airplane wings), in civil engineering where the design of long-span bridges is now partly governed by wind effects, and in biomechanics (blood flows in arteries, for instance). Very roughly, the coupling between the structure and the flow can be described as follows: the structural displacements modify the geometry of the fluid domain, hence the fluid flow itself which in turn exerts an action on the structure. The effects of structural displacements on the fluid can be taken into account using ALE techniques, but the corresponding direct simulations are highly CPU-intensive, which makes stability analyses of such coupled problems very costly from a computational point of view. In this context a major objective of our work has been to formulate a simplified model of the fluid-structure interaction problem in order to allow computational assessments of stability at a reasonable cost.

3.3. Modeling and estimation in biomechanics

A keen interest in questions arising from the need to model biomechanical systems – and to discretize such problems – has always been present in the team since its creation. Our work in this field until now has been more specifically focused on the objectives related to our participation in the ICEMA ARC projects and in the CardioSense3D initiative, namely, to formulate a complete continuum mechanics model of a beating heart, and to confront – or "couple", in the terminology of the INRIA strategic plan – numerical simulations of the model with actual clinical data via a data assimilation procedure.

Our global approach in this framework thus aims at using measurements of the cardiac activity in order to identify the parameters and state of a global electromechanical heart model, hence to give access to quantities of interest for diagnosing electrical activation and mechanical contraction symptoms. The model we propose is based on a chemically-controlled constitutive law of cardiac myofibre mechanics consistent with the behavior of myosin molecular motors [20]. The resulting sarcomere dynamics is in agreement with the "sliding filament hypothesis" introduced by Huxley. This constitutive law has an electrical quantity as an input which can be independently modeled, considered as given (or measured) data, or as a parameter to be estimated.

4. Application Domains

4.1. Application domains

Our researches have natural applications in all sectors of the mechanical industry: car and naval industries; aeronautics and space; civil engineering; tires; MEMs and nanotechnologies...

We also actively seek new applications in biotechnologies, although of course the economy and structuring of this sector is not as developed yet.

5. Software

5.1. FELISCE

Participants: Dominique Chapelle, Jérémie Foulon [correspondant], Philippe Moireau, Marina Vidrascu.

FELISCE – standing for "Finite Elements for LIfe SCiences and Engineering" – is a new finite element code which the MACS and REO teams have decided to jointly develop in order to build up on their respective experiences concerning finite element simulations. One specific objective of this code is to provide in a unified software environment all the state-of-the-art tools needed to perform simulations of the complex cardiovascular models considered in the two teams – namely involving fluid and solid mechanics, electrophysiology, and the various associated coupling phenomena. FELISCE is written in C++, and may be later released as an opensource library. https://gforge.inria.fr/projects/felisce/

5.2. HeartLab

Participants: Matthieu Caruel, Radomir Chabiniok, Dominique Chapelle, Alexandre Imperiale, Philippe Moireau [correspondant].

The heartLab software is a library written in Matlab and C (mex functions) designed to perform both simulation and estimation (based on various types of measurements, e.g. images) of the heart mechanical behavior. Started in 2006, it is already quite large (about 60,000 lines), and is used within the CardioSense3D community.

The code relies on OpenFEM for the finite element computations, and the implementation was performed with a particular concern for modularity, since modeling and estimation use the same finite element operators. This modularity also allows to couple the code with other FEM solvers, such as LifeV and Mistral developed in the Reo team-project. In particular, we are now able to include perfusion and electrical coupling with LifeV using PVM, and fluid-structure interaction using Mistral.

We also included geometric data and tools in the code to define heart anatomical models compatible with the simulation requirements in terms of mesh quality, fiber direction data defined within each element, and referencing necessary for handling boundary conditions and estimation, in particular. These geometries are analytical or come from computerized tomography (CT) or magnetic resonance (MR) image data of humans or animals.

We recently incorporated numerous non-linear data assimilation observation operators based on medical imaging post-processing to be able to now perform estimation with a large variety of medical imaging modalities.

The Library is now 64 bits compatible with the help of the Cesare Corrado from Reo.

5.3. MITCNL

Participants: Dominique Chapelle, Marina Vidrascu [correspondant].

The package MITCNL is a set of subroutines that implements the triangular MITC3, MITC6 and quadrilateral MITC4 and MITC9 shell elements for large displacements [14]. We use it as a basis for new developments of shell elements, in particular within Modulef. It can be easily interfaced with most finite element codes as well. We also license this package to some of our partners for use with their own codes.

5.4. MODULEF

Participant: Marina Vidrascu [correspondant].

Most of the software developed in our team is integrated in the Modulef library. Modulef is designed to provide building blocks for effective and reliable software development in finite element analysis. Well-adapted rigorous data structures and ease of integration (for new methods or algorithms) are some of its key advantages. Until 1998, Modulef was distributed by the Simulog company within a club structure (for a membership fee). In order to encourage its dissemination, its status was then changed to make it freely available. It can be downloaded at no charge from the INRIA-Rocquencourt web site (http://www-rocq.inria.fr/modulef/).

5.5. OpenFEM: a Finite Element Toolbox for Matlab and Scilab

Participants: Dominique Chapelle, Philippe Moireau [correspondant].

OpenFEM (http://www.openfem.net) is an *opensource* finite element toolbox for linear and nonlinear structural mechanics within the Matlab and Scilab matrix computing environments. This software is developed in a collaboration between Macs and the SDTools company [1]. Performing finite element analyses within a matrix computing environment is of considerable interest, in particular as regards the ease of new developments, integration of external software, portability, post-processing, etc.

This Library is the core of the finite element computations of HeartLab where a specific version have been developed with the help of Cesare Corrado from Reo.

5.6. SHELDDON

Participants: Dominique Chapelle, Marina Vidrascu [correspondant].

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[1] http://www.sdtools.com

SHELDDON (SHELls and structural Dynamics with DOmain decomposition in Nonlinear analysis) is a finite element library based on the Modulef package which contains shell elements, nonlinear procedures and PVM subroutines used in domain decomposition or coupling methods.

5.7. Verdandi

Participants: Dominique Chapelle, Marc Fragu [correspondant], Vivien Mallet, Philippe Moireau.

Verdandi is an opensource (LGPL) software library aiming at providing assimilation data methods and related tools. Mainly targeted at large systems arising from the discretization of PDEs, it is intentionally devised as generic, which allows for applications in a wide range of problems (biology and medicine, environment, image processing...). See also the web page http://verdandi.gforge.inria.fr/, with a complete documentation in English. The first stable version (1.0) was released in June and contains most of the major data assimilation algorithms of both variational and sequential types. Moreover, some specific developments are performed with particular regard to cardiac modeling applications, as Verdandi is partly funded by – and distributed within – the euHeart project.

- ACM: Mathematical software
- AMS: System theory; control
- Software benefit:Verdandi est la seule bibliothèque d'assimilation de données générique.
- License: LGPL (2.1 or any later version)
- Type of human computer interaction: Ligne de commande et fichiers de configuration
- OS/Middelware: Linux, MacOS ou Windows
- Required library or software: Seldon (LGPL, http://seldon.sourceforge.net/)
- Programming language: C++, ISO/IEC 14882: I998(E)Python, version 2.6
- Documentation: Chaque fonction est documentée, grâce à Doxygen. Il y a aussi un guide d'utilisation (en cours de rédaction actuellement). Toute la documentation est en anglais.

6. New Results

6.1. Modeling and estimation in biomechanics

6.1.1. *Patient-Specific Electromechanical Models of the Heart for the Prediction of Pacing Acute Effects in CRT: a Preliminary Clinical Validation*

In collaboration with Project-Team Asclepios from INRIA Sophia-Antipolis-Méditerranée and the Division of Imaging Sciences of St Thomas' Hospital, King's College London we demonstrated the benefits of using patient-specific electromechanical models of the heart for the prediction of pacing acute effects in CRT, see [5].

Cardiac resynchronisation therapy (CRT) is an effective treatment for patients with congestive heart failure and a wide QRS complex. However, up to 30% of patients are non-responders to therapy in terms of exercise capacity or left ventricular reverse remodelling. A number of controversies still remain surrounding patient selection, targeted lead implantation and optimisation of this important treatment. The development of biophysical models to predict the response to CRT represents a potential strategy to address these issues. We present how the personalisation of an electromechanical model of the myocardium can predict the acute haemodynamic changes associated with CRT. In order to introduce such an approach as a clinical application, we needed to design models that can be individualised from images and electrophysiological mapping of the left ventricle. We performed the personalisation of the anatomy, the electrophysiology, the kinematics and the mechanics. The acute effects of pacing on pressure development were predicted with the in silico model for several pacing conditions on two patients, achieving good agreement with invasive haemodynamic measurements: the mean error on dP/dtmax is 47.5 ± 35 mmHg.s-1, less than 5% error.

6.1.2. *Estimation of tissue contractility from cardiac MRI using a biomechanical heart model*

Participants: Radomir Chabiniok, Dominique Chapelle, Alexandre Imperiale, Philippe Moireau.

In collaboration with P.-F. Lesault, A. Rahmouni and J.-F. Deux from Hospital H. Mondor, Créteil we proposed and assessed an estimation procedure – based on data assimilation principles – well-suited to obtain some regional values of key biophysical parameters in a beating heart model, using actual Cine-MR images, see [8], [1]. The motivation is twofold: (1) to provide an automatic tool for personalizing the characteristics of a cardiac model in order to achieve predictivity in patient-specific modeling, and (2) to obtain some useful information for diagnosis purposes in the estimated quantities themselves. In order to assess the global methodology we specifically devised an animal experiment in which a controlled infarct was produced and data acquired before and after infarction, with an estimation of regional tissue contractility – a key parameter directly affected by the pathology – performed for every measured stage. After performing a preliminary assessment of our proposed methodology using synthetic data, we then demonstrate a full-scale application by first estimating contractility values associated with 6 regions based on the AHA subdivision, before running a more detailed estimation using the actual AHA segments. The estimation results are assessed by comparison with the medical knowledge of the specific infarct, and with late enhancement MR images. We discuss their accuracy at the various subdivision levels, in the light of the inherent modeling limitations and of the intrinsic information contents featured in the data.

We are now working on improving these results by the use of Tagged-MRI, see [9]. The first approach consists in assuming that the image data is processed in the form of deforming tag planes, which we employ to obtain a discrepancy between the model and the data by computing distances to these surfaces. We assess our procedure using synthetic measurements produced with a model representing an infarcted heart as observed in an animal experiment, and the estimation results are found to be of superior accuracy compared to assimilation based on segmented endo- and epicardium surfaces. Then we extend this strategy to tagged lines instead of tagged planes or even directly with apparent displacements extracted from tagged images by optical flow methods.

6.1.3. *Convergence of observers based on partial field measurements for the wave equation*

Participants: Dominique Chapelle, Nicolae Cîndea, Maya de Buhan, Philippe Moireau.

We analyzed an observer strategy based on partial – i.e. in a subdomain – measurements of the solution of a wave equation, in order to compensate for unknown initial conditions, see [17], [18]. We proved the exponential convergence of this observer under a non-standard observability condition, whereas using measurements of the time-derivative of the solution would lead to a standard observability condition arising in stabilization and exact controlability. Nevertheless, we directly related our specific condition to the classical geometric control condition. This results justify in a linear framework the use of our observer-based filter in cardiac modeling.

6.1.4. *Reduced nonlinear optimal filtering*

Participants: Dominique Chapelle, Akos Matszangosz, Philippe Moireau.

We investigated some issues pertaining to reduced-order considerations in nonlinear optimal filtering. Classically, optimal filtering formulations lead to Hamilton-Jacobi-Bellman (HJB) equations posed in the complete "space of uncertainty", namely, including the state space. This makes such methods generally untractable for PDE-based models. However, under certain assumptions pertaining to reduced uncertainties we can transform the HJB equations into a form posed in the reduced uncertainty space, and with only time derivatives involved. This form can be solved for – including with PDEs – provided this reduced space is of limited size, and then gives a reference "optimal" method to which other filtering procedures can be compared. The subject of Akos Matszangosz' internship (from "Ecole des Mines de Paris", duration 4 months) was to design and perform an adequate implementation of this reduced-order optimal filter, based on a sparse-grid discretization of the uncertainty space. In addition, we are currently working on discrete-time optimal filtering formulations, which are distinct – and preferable in principle – to discretizing the continuous forms.

6.2. Asymptotic and multiscale modeling

6.2.1. *Modeling and simulation of multi-layers mechanical structures*

Participants: Marina Vidrascu, Sofiene Hendili.

The collaboration with Françoise Krasucki (Montpellier University) and Giuseppe Geymonat (Ecole polytechnique) on the modeling of 3D materials connected by stiff interfaces continues within the Epsilon ANR project (Domain decomposition and multi-scale computations of singularities in mechanical structures 7.1.1). In the framework of matched asymptotic expansions we introduced a new effective and robust method to approximate the behavior of a structure containing a thin layer with periodically distributed heterogeneities (holes, rigid bodies...), see [3], [10], [11].

6.2.2. *Multi-scale modeling and simulation of rubber*

Participants: Maya de Buhan, Marina Vidrascu, Antoine Gloria [SIMPAF], François Lequeux [ESPCI], Patrick Le Tallec [Ecole Polytechnique].

In collaboration with A. Gloria (project-team SIMPAF) and P. Le Tallec (Ecole Polytechnique), we are currently working on a multiscale model for rubber based on the statistical physics description of a network of polymer chains. The numerical simulation of the model has been addressed within the ARC Disco using the Shelddon software. Comparisons with mechanical experiments are promising, and related inverse problems have been addressed in the post-doc of M. de Buhan. Two publications are in preparation.

This work is supported by the ARC DISCO (7.1.2).

6.3. Other topics

6.3.1. *Numerical analysis of POD-based Galerkin approximations*

Participants: Dominique Chapelle, Asven Gariah, Philippe Moireau, Jacques Sainte-Marie.

In [2], we proposed a numerical analysis of Proper Orthogonal Decomposition (POD) model reductions in which a priori error estimates are expressed in terms of the projection errors that are controlled in the construction of POD bases. These error estimates are derived for generic parabolic evolution PDEs, including with non-linear Lipschitz right-hand sides, and for wave-like equations. A specific projection continuity norm appears in the estimates and — whereas a general uniform continuity bound seems out of reach – we prove that such a bound holds in a variety of Galerkin bases choices. Furthermore, we directly numerically assess this bound – and the effectiveness of the POD approach altogether – for test problems of the type considered in the numerical analysis, and also for more complex equations. Namely, the numerical assessment includes a parabolic equation with super-linear reaction terms, inspired from the FitzHugh-Nagumo electrophysiology model, and a 3D biomechanical heart model. This shows that the effectiveness established for the simpler models is also achieved in the reduced-order simulation of these highly complex systems.

This work is now being continued in order to handle parameter-dependent models, and thence estimation problems.

6.3.2. *Sail modeling*

Participants: Dominique Chapelle, Daniele Trimarchi, Marina Vidrascu.

A dynamic Finite Element method – based on non-linear MITC shell finite elements implemented in the MITCNL software – has been proposed and assessed for the analysis of downwind sail-type structures, see [12]. The main purpose was here to investigate the development of wrinkling, a phenomenon commonly observed in practice for such structures. Considering the wrinkling in this type of analysis is of great interest, since wrinkling affects the stress distribution in the fabric. Further developments primarily regard various refinements of the model, in order to represent some even more realistic sail configurations such as with non-isotropic material models, corner reinforced zones, and cable boundary conditions. Of course, another very important perspective – and work in progress, indeed – concerns the use of such sail models coupled with the wind flow in a fluid-structure interaction framework.

7. Partnerships and Cooperations

7.1. Regional Initiatives

7.1.1. *Epsilon*

The Epsilon project is an ANR project entitled "Domain decomposition and multi-scale computations of singularities in mechanical structures". The members are Ecole Polytechnique, I3m at Montpellier, Laga at Paris-Nord and INRIA. INRIA is particularly involved in the modeling and simulation of an assembly of structures containing a very thin layer embedded in a 3D structure. This is the subject of the PhD thesis of Sofiene Hendili (co-supervised by Montpellier and INRIA)

7.1.2. *DISCO*

DISCO[2] (du DIScret au COntinu pour les polymères réticulés) is an INRIA ARC. The members are EPI SIMPAF (Antoine Gloria) and MACS (Maya de Buhan and Marina Vidrascu) from INRIA, Ecole polytechnique, ESPCI, and the Max Planck Institute for Mathematics in the Sciences (Leipzig). The leader is Antoine Gloria (EPI SIMPAF). The main objective is the design, mathematical analysis, numerical analysis, and numerical simulation of discrete models for rubber. A workshop was organized in January 2011.

7.2. European Initiatives

7.2.1. *FP7 Projects*

7.2.1.1. euHeart

Title: euHeart

Type: COOPERATION (ICT)

Defi: Virtual Physiological Human

Instrument: Integrated Project (IP)

Duration: June 2008 – May 2012

Coordinator: Philips Technologie GmbH Forschungslaboratorien (Germany)

Others partners: Univ. Oxford, Universitat Pompeu Fabra (Barcelona), Univ. Sheffield (UK), King's College London, Academic Medical Center (Amsterdam), Univ. Karlsruhe, INSERM, Philips Medical Systems, Berlin Heart, Hemolab (Eindhoven), Deutsche Krebsforschungszentrum Heidelberg, Volcano Europe (Brussels), Boston Scientific (Spain), Hospital Clínico San Carlos de Madrid

See also: http://www.euheart.eu/

Abstract: The euHeart Project is a European FP7 project of the IP category. It combines seventeen industrial, clinical and academic partners, whose collective goal is the development of individualized, computer-based, human heart models. Using comprehensive, patient-specific data as the basis for their design, these models will provide insight into the origin and progression of specific disease patterns, including those associated with heart failure, heart rhythm disorders, coronary artery disease, and aortic disease. Within this project, the Macs team is more specifically in charge of coordinating one workpackage entitled "Biophysical model personalisation", which consists in developing some methodological and software tools to solve the inverse problems of concern in the applications considered in the project.

7.2.1.2. VPH-Share

Title: VPH-Share

Type: COOPERATION (ICT)

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[2]http://chercheurs.lille.inria.fr/~gloria/DISCO.html

Defi: Virtual Physiological Human

Instrument: Integrated Project (IP)

Duration: March 2011 – February 2015

Coordinator: Univ. Sheffield (UK)

Others partners: Cyfronet (Cracow), University College London, Istituto Ortopedico Rizzoli (Bologna), NHS, IBM Israel, Univ. Auckland, Agència d'Informació, Avaluació i Qualitat en Salut (Barcelona), Biocomputing Competence Centre (Milano), Universitat Pompeu Fabra (Barcelona), Philips Research, TUE (Eindhoven), Sheffield Teaching Hospitals, Atos Origin (Madrid), the Open University (UK), Univ. Vienna, King's College London, Empirica (Bonn), Fundació Clínic (Barcelona), Univ. Amsterdam

See also: http://vph-share.org/

Abstract: VPH-Share aims at developing the organisational fabric (the infostructure) and integrate the optimised services to expose and share data and knowledge, to jointly develop multiscale models for the composition of new VPH workflows, and to facilitate collaborations within the VPH community. Within this project, the Macs team is in charge of developing some high-performance data assimilation software tools.

7.3. International Initiatives

7.3.1. INRIA Associated Teams

7.3.1.1. CARDIO

Title: Mathematical modelling and Numerical Simulation for Cardiovascular Applications

INRIA principal investigator: Philippe Moireau

International Partner:

      Institution: Stanford University (United States)

      Laboratory: Bioengineering and Surgery Departments

      Researcher: Charles TAYLOR

International Partner:

      Institution: UC San Diego (United States)

      Laboratory: Mechanical and Aerospace Engineering

      Researcher: Alison MARSDEN

Duration: 2011–2013

See also: https://idal-siege.inria.fr/cardio/

To improve disease understanding, surgical repair or medical device design, mathematical and numerical tools have been the subject of much efforts over the last decades. In this context, we propose a research subject on cardiovascular and air flow modeling. It extends the project of the previous associated team on blood flow modeling to flow of air in the lungs. The goal is to continue to work on bringing together methods developed in the different teams, to compare them if necessary, and to apply them to in-vivo (animal or human) physiologically relevant situations. All the different team members have a strong will to work close to the applications. They all have links to clinicians or biologists, which drive the concrete applications that will be studied: congenital heart disease pathophysiology and repair, artery wall compliance study in normal and pathophysiological cases, heart valve pathophysiology assessment, aerosol deposition in the lungs. Furthermore, the associated team facilitates the breadth of researcher knowledge by exposure to different ways of thinking, methods and/or applications, and by the training of students as they interact with the other institutes.

8. Dissemination

8.1. Animation of the scientific community

Dominique Chapelle

- Speaker at FIMH'11 (NYC, USA, May 25–27), 6th MIT Conference on Computational Mechanics (Boston, USA, June 15–17), IFIP'11 (Berlin, RFA, Sept. 12th), "Journée SMAI Maths-Industrie Voile" (Paris, Dec. 9th)

- Seminars at Ecole Polytechnique (Ladhyx, Febr. 7th), ESPCI (Febr. 22nd), Univ. Grenoble (LJK, May 12th), Harvard (June 6th)

- PhD thesis referee for E. Lignon (Ecole Polytechnique, Jan. 21st) and M. Caruel (Ecole Polytechnique, Oct. 10th)

Sofiane Hendili

- Speaker at 10ème Colloque National en Calcul des Structures CSMA 2011, 9-13 Mai 2011, Giens

- Speaker at 20ème Congrès Français de Mécanique CFM 2011, 28 Aout au 2 Septembre 2011, Besançon

Philippe Moireau

- Attending the conference Functional Imaging and Modeling for the Heart FIMH'11, where 2 proceedings were accepted as a poster and an oral presentation given by D. Chapelle,

- Speaker at "Contact Innovation" on "Patient-specific bio-physical modeling for the heart", 15 Nov. 2011, Ministère de la Recherche, Paris.

- Speaker at "Horizon Maths" on "Joint state parameter estimation for PDEs by observer and optimal filtering", 12-13 Dec. 2011, Areva, Paris

- Lecture "La météo du cœur" at award ceremony for "Olympiades de Mathématiques" (Versailles academic district), 15 June

Daniele Trimarchi

- Speaker at 10ème Colloque National en Calcul des Structures CSMA 2011, 9-13 May 2011, Giens

Marina Vidrascu

- with A. Gloria, P. Le Tallec and F. Lequeux, organization of the workshop "From polymer physics to rubber elasticity" January 17–19 IHP (Paris)

- Seminars: Univ. Amiens (June 6th), Laboratoire JLL (Oct. 10th), Univ. Orsay (Nov. 24th)

8.2. Teaching

Philippe Moireau

Master : "MA103 - Introduction aux EDP et à leur approximation numérique", 14h, M1, ENSTA ParisTech, France

Master : "MA201 - La méthode des éléments finis", 14h, M2, ENSTA ParisTech, France

PhD supervisions

> PhD: Asven Gariah, "Réduction de modèles complexes pour la simulation et l'estimation, Application à la modélisation cardiaque", UPMC, December 9th 2011, D. Chapelle and J. Sainte-Marie

> PhD in progress: Sofiène Hendili, "Décomposition de domaines et calculs multi-échelles dans les structures mécaniques", started October 2009, Françoise Krasucki and Marina Vidrascu

> PhD in progress: Daniele Trimarchi "Analysis of downwind sail structures using nonlinear shells finite elements: wrinkle development and fluid interaction effects", started January 2009, Stephen Turnock (Univ. Southampton)

> PhD in progress: Alexandre Imperiale, "Image-based observation operators for data assimilation in cardio-mechanics" , UPMC, started October 2010, D. Chapelle and P. Moireau

9. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journal

[1] R. CHABINIOK, P. MOIREAU, P.-F. LESAULT, A. RAHMOUNI, J.-F. DEUX, D. CHAPELLE. *Estimation of tissue contractility from cardiac cine-MRI using a biomechanical heart model*, in "Biomechanics and Modeling in Mechanobiology", 2011 [*DOI :* 10.1007/S10237-011-0337-8], http://hal.inria.fr/hal-00654541/en.

[2] D. CHAPELLE, A. GARIAH, J. SAINTE-MARIE. *Galerkin approximation with Proper Orthogonal Decomposition: new error estimates and illustrative examples*, in "ESAIM: Mathematical Modelling and Numerical Analysis", 2011 [*DOI :* 10.1051/M2AN/2011053], http://hal.inria.fr/hal-00654539/en.

[3] G. GEYMONAT, S. HENDILI, F. KRASUCKI, M. VIDRASCU. *The matched asymptotic expansion for the computation of the effective behavior of an elastic structure with a thin layer of holes*, in "International Journal for Multiscale Computational Engineering", 2011, vol. 9, n$^{\text{o}}$ 5, p. 529-542 [*DOI :* 10.1615/INTJMULTCOMPENG.V9.I5], http://hal.inria.fr/inria-00540992/en.

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