Curriculum Vitae

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1) Brief Curriculum Vitae

Year	*Position*
since 2001	Maître de Conférence at Nantes University (UN), Applied Math team of LMJL
2000 - 2001	Postdoctoral fellow of the INRIA team Sinus (J.A. Desideri), Sophia Antipolis.
2000	Ater at LATP, Aix-Marseille university (T. Gallouët, R. Herbin).
1999	Ater at GMM, INSA of Toulouse. Member of MIP (J.P. Vila).
1994 - 1998	Phd Student at Onera - Cert (Toulouse). Phd Thesis from University Paul Sabatier (Toulouse 3) obtained in January 1999, under the scientific direction of J.P. Vila and P. Villedieu.
1994	DEA from University Paul Sabatier (Toulouse 3) and Supaéro
1991 - 1994	Engineer from Supaéro (Toulouse).

Introduction

My background is in aeronautic and aerospace engineering (Supaéro) and applied mathematics (University Paul Sabatier, Toulouse 3). My main interests are in

- PDE approximation, numerical analysis of finite volume methods;
- Application to CFD, and currently to problems in biology and medicine;
- Scientific Computing issues in 3D complex simulations.

Currently, my main interest is in finite volume methods and biomedical applications. I was the supervisor of the PhD thesis of C. Pierre from 2002 to 2005 and I recently get a 4 year financial support from the french ANR for a project called MOMME concerning mathematical

methods and models for the simulation of the electrical behaviour of the heart (see next section). It involves interactions with researchers from various fields, like physiology and medical imaging.

It is a field that I am already involved into as a member of CS3D, a large action from INRIA concerning the electro-mechanical modeling of the heart, and as the correspondng member of the GDR MABEM from the CNRS (supervised by D. Bresch and E. Grenier).

In parallel I am involved in several academic collaboration for the numerical analysis of new finite volume methods for anisotropic and heterogeneous diffusion operators and convection-diffusion problems (F. Hubert – Marseille, M. Manzini – Pavia, C. Pierre – Pau); and for the analysis of the bidomain equations of electrocardiology (Y. Bourgault – Ottawa).

Part of my research work concerns scientific computing issues : methodology, tools and developpement of numerical codes.

As a researcher, I am involved in teaching graduate students (Master) the mathematics of finite volume methods or modeling in electrophysiology.

2) Research Activities

Momme project

I am the coordinator of the ANR project Momme (for *Méthodes et MOdélisation Mathématiques en Électrocardiologie*). It includes a financial support for 4 years, with postdoctoral positions.

The project starts on December 2007 and aim at improve our knownledge of the the electrical behaviour of the heart and the ECG patterns, through mathematical modeling and numerical methods. It involves various types of equations, Hamilton-Jacobi eqs, integral eqs and reaction-diffusion systems of eqs; and numerical methods like finite volumes, fast-sweeping algorithms, fast-multipole methods, in order to understand and simulate the electrical behaviour of the heart and the electrocardiogram.

MMCE Conference

Together with this project, a conference is organized in Nantes. Its goal is to gather mathematicians working in the field of modelisation, analysis, approximation, numerical analysis and scientific computing applied to electrocardiology.

Even though this conference is mainly run by mathematicians, there is a strong will of opening towards the concerned fields of biology and medical imaging, especially towards researchers and students who work on the interface between these fields and wish to strengthen their knowledge.

The web site is www.math.sciences.univ-nantes.fr/MMCE09

Finite Volume Methods, Diffusion operators, Automatic Mesh Refinement

Since I started my PhD, I studied finite volume methods for the approximation of convection-diffusion problems, with mesh adaptation. The main difficulty is to construct an accurate and robust finite volume discretization of anisotropic and heterogeneous diffusion on very general

meshes. It has various applications for instance to CFD with automatic mesh refinement, to porous media problems (very anisotropic, heterogeneous, with quite irregular meshes) and also to cardiac simulation (anisotropic, heterogeneous, with very irregular meshes as obtained from medical imaging).

I developed a new approach to the computation of complex numerical fluxes of diffusion, that is called the *Diamond Scheme*. The numerical analysis of this family of method have been carried out in [9, 8, 6], where various error estimates are proved, especially on AMR meshes.

During my post-doctoral period at Sophia-Antipolis, I have also been working with A. Dervieux on anisotropic *vs* isotropic mesh refinement. We proved that anisotropic refinement may be necessary to recover a correct convergence rate of numerical approximations [5].

In the context of electrocardiology, I developed during the PhD of C. Pierre a new 3D finite volume method for anisotropic heterogeneous diffusion [16]. I am currently improving this 3D method with F. Hubert in [31] where nice results of convergence and error estimates are expected, and using it in the context of convection-diffusion with M. Manzini [2].

Finite Volume Methods, Hyperbolic Systems of Equations

I have also been working during my PhD on linear symmetric hyperbolic systems of equations (Maxwell's or acoustics' eqs.) on a bounded domain. I introduced new proofs of numerical stability and optimal convergence rate ($O(h^{1/2})$ on meshes of size h for a piecewise constant approximation) in [7] for explicit discretization of time-dependant problems. The results especially explains how the boundary condition has to be discretized in an upwind manner.

Reaction-diffusion Systems of Equations in Electrocardiology

I started to study the electrical behaviour of the heart during my postdoctoral period with J.A. Desideri. So far, I have been a collaborator of the INRIA projects ICEMA and ICEMA-2. I am currently a member of CS3D, a project that focuses on the electro-mechanical modeling of the heart and clinical applications thereof. It involves various academic, clinical and industrial partners.

My personal work in electrocardiology focuses on the theoretical and numerical study of the *monodomain* and *bidomain* equations. Stability and convergence results of a finite volume method have been proved [4, 20, 16] with C. Pierre, resulting in practicals tools [12, 23, 24, 18] with M. Sermesant. Additionally a new proof of existence for global solutions to the bidomain equations for quite general models [3] has been published with Y. Bourgault. Pr. Y. Bourgault is regular collaborator. We are currently working on a new theoretical tool to compare the bidomain and monodomain operators, using some symbolic computations.

Modeling and Scientific Computing in Biology and Medicine

The actual 3D computation of the solution to realistic models of the myocardium necessitates complex and sophisticated scientific computing tools. Fine 3D meshes are necessary to account for up to date ionic models; a large, sparse but ill-conditioned system of equations must be solved at each time-step.

I choose two strategies to tackle these difficulties : construct intermediate models, and using modern technical tools of scientific computing. Hence I supervised the postdoctoral period of C. Olah (2007) on the idea of POD (Proper Orthogonal Decomposition) as a reduction model technique to obtain preconditioners. It is work in progress for which results are expected.

The most simplified models are Eikonal equations, that simply model the propagation of the activation front in the bidomain system of reaction diffusion equations. We successfully used it in a clinical context where real-time computation is needed [11, 10]. Finite Volume discretizations and Fast Marching and more recently Fast Sweeping algorithms are of great interest in this context. The challenge concerning these techniques is to use unstructured very irregular 3D meshes and to solve anisotropic equations.

In parallel , with R. Turpault (LMJL), we are working on intermediate models using either modified monodomain equations or Eikonal equations together with integral equations to model and compute the electrical behaviour of the heart and the electrocardiogram.

All these ideas are to be developped as part of the ANR project Momme.

Development of computer codes, softwares

Since I have been working for the Inria project Icema (continued with Icema-2 and CS3D, I developed first a 3D code together with M. Sermesant for the solution to the monodomain equations. It is part of a large code developped by the team asclepios from the Inria [12]. It has been partially validated through comparisons with the literature and experimental data [23, 22].

During the PhD of C. Pierre, we developped a 3D code for the solution of the bidomain equations [29, 15].

The code has also been used by M. Pop (Dep. of Medical Biophysics of the University of Toronto) in an experimental framework [17, 18, 19] : numerical results are used to validate clinical hypotheses on the apparition of spiral propagation waves after ventricular tachycardia.

At last, software development is also part of the project Momme : we aim at developing a 3D parallel framework for the implementation of new models and methods within our research program. The software is accessible to the members through the subversion server svn.math.cnrs.fr/MOMME.

Collaborations

- Collaboration with G. Manzini (CNR-IMATI, Pavia). He has been invited for 1 month in Nantes. I went for 1 month in Pavia as an invited professor in July 2008. We have been working on the extension to convection-diffusion problems of the DDFV finite volumes methods [2], with the Italian support of the *Gruppo Nationale per il Calcolo Scientifico*.
- With F. Hubert (LATP, Univ. Provence), I work on the numerical analysis of 3D DDFV methods. This collaboration is supported by the GdR MoMas (CNRS) [14, 31]
- With M. Pop (Department of Medical Biophysics of the University of Toronto,*Health Science Center, SunnnyBrooks & Womens hospital*), I have some work in progress on validation of the numerical simulations of the bidomain equations. [17, 18, 19].

- I collaborate to CS3D and in particular with M. Sermesant [22, 23, 24, 13, 12, 11] on 3D scientific computing applied to medical imaging and electrocardiac simulation.
- With Pr. Y. Bourgault (Department of mathematics and Statistics, Univ. Ottawa, Canada)) I collaborate on numerical simulation and analysis of the bidomain equations [3, 30].
- With A. Dervieux (INRIA) [5] I collaborated on mesh adaptation.
- With T. Gallouët and R. Herbin [6], J.-P. Vila et P. Villedieu [7, 8, 9], I worked on Analysis of Finite Volume Methods.

Invitations and visiter positions

Place	*Year*	*Duration*	*Comment*
University of Ottawa	2003	3 weeks, november	invitation from Pr. Y. Bourgault
King's College, London	2005	1 week, march	invitation *Cardiac MR Research Group*
University of Ottawa	2005	4 weeks, june/july	invitation from Pr. Y. Bourgault
University of Ottawa	2006	3 weeks, march/april	invitation from Pr. Y. Bourgault
IMATI-CNR, Pavia	2008	4 weeks, september	invited professor *GNCS*
University of Ottawa	2008	2 weeks, september	invitation from Pr. Y. Bourgault

Supervising Activities

A list of my supervising/co-supervising activities is in table 1.

- J. Oniboni had a financial support from INRIA.
- C. Pierre had a scholarship from the french Ministry of Research (MENESR). After a postdoctoral period at University of Ottawa (CRM Fellowship), he is now a CNRS Research Engineer at University of Pau.
- C. Olah had a fellowship from the CNRS for 12 months. She occupies currently a postdoctoral position at the University of Laval in Canada.
- Two postdoctoral fellowships are available in the ANR project MOMME.

Name	Year	Position/Role	Title
N. Jullian	1999	DEA, Co-supervisor	Finite Volume Methods and Anisotropic Diffusion
J. Oniboni	2001	Engineer, Supervisor	POD reduced order model derived from the monodomain eqs. of the Myocardium [35]
C. Pierre	2002-2005	PhD Thesis, co-supervisor	Modeling and Computing the Electrical Activity of the Heart
C. Olah	2007	Postdoctoral supervisor	POD Preconditioning for the bidomain eqs.
R. Cchay	2007	Master 2, Supervisor	Fast Sweeping Method for the Eikonal eqs. on unstructured meshes
A.K. Assani	2007	Master 2, Supervisor	Fast-Sweeping Method for Anisotropic Hamilton-Jacobi eqs.
A. Uzureau	2009	Master 2, Supervisor	Modeling and computing the osteogenesis process

Table 1: Supervising Activities

I wrote paper reviews for the following journals:

JCP, Num. Meth. PDE, Num. Math, M2AN, IJFV, SIAM Numerical Analysis,
Int. J. for Num. Meth. in Eng.

Grants, Prizes, ...

- ANR Grant for a 4 years project (MOMME) concerning models and Mathematical Method in Electrocardiology. It includes 2 post-doctoral positions.
- Research and Doctoral Supervising Grant from the French Ministry of Research (*PEDR* for 2003-2007 and 2007-2011).
- Invited position of Professor for 1 months at CNR-IMATI, Pavia, Italy, obtained from the Italian *Gruppo Nationale per il Calcolo Scientifico*.
- Special financial support from the CNRS for a shared memory parallel computer (2004).
- Fellowships for the PhD thesis of Charles Pierre (MENESR, 2002-2005) and for the post-doctoral position of C. Coros-Olah (CNRS, 2006-2007).
- Financial support for a collaboration with F. Hubert within the project of R. Herbin in the GDR MOMAS.
- Financial support from the University of Nantes for the invitations of Pr. Y. Bourgault (June 2004), and M. Manzini (CNR, IMATI, June 2007).

Oral communications

Below is a list of the most recent or important talks that I had the occasion to give.

Week entitled "Avancées récentes en calcul scientifique", CIRM, february 2009
"Mathematical Models and Methods in Electrocardiology";

GDR Momas meeting, novembre 14th, 2008
"Quelques schémas DDFV en 3D";

Institut du Thorax, UMR 915 Inserm - Université de Nantes, november 7th, 2008

"Modèles et méthodes mathématiques en électrocardiologie";

GDR CNRS Mabem meeting, University of Nice, october 15th, 2008
"Numerical Simulations in Electrocardiology ";

University of Ottawa, septembre 17th, 2008
"Numerical Simulations in Electrocardiology";

IMATI-CNR, Pavia, july 8th, 2008
"A 3D DDFV finite volume method for heterogeneous and anisotropic diffusion equations. Application to Electrocardiology";

Universita di Milano, july 9th, 2008
"Numerical Simulations in Electrocardiology";

M.O.X., Politechnico di Milano, july 7th, 2008
"Mathematical Models and Methods in Electrocardiology";

GDR Momas workshop, june 2006
"Un schéma volumes finis en dualité discrète 3D, application au système bidomaine de l'éléctrocardiologie";

CEA-EDF-INRIA school, april 2004
"Finite Volume Approximation of the FitzHugh-Nagumo Equations";

University of Ottawa, novembre 28th, 2003
"Analytical and Numerical Study of the FitzHugh-Nagumo System and its Stability".

3) Teaching Activities

My past and present teaching activities include in particular

École Centrale de Nantes (ECN) : applied and numerical analysis;

Research Master 2: course on Finite Volume Methods (2001-2002 and 2008-2009) and course on Reaction-Diffusion eqs. (2006-2007).

Professional Master 2 : since 2005, I teach a course on finite volume approximation of non-linear hyperbolic eqs.

Master 1 : functional analysis, numerical analysis.

Licence : basic numerical analysis techniques.

4) Publications

Articles

[1] Y. Coudière, C. Pierre, and R. Turpault. A 2d/3d discrete duality finite volume scheme. application to ecg simulation. *International Journal on Finite Volumes (accepted for publication)*, 2009. http://hal.archives-ouvertes.fr/hal-00328251/fr.

[2] Y. Coudière and M. Manzini. The discrete duality finite volume method for convection-diffusion problems. *SIAM Journal on Numerical Analysis (accepted for publication)*, 2009. http://hal.archives-ouvertes.fr/hal-00319254/fr/.

[3] Y. Bourgault, Y. Coudière, and C. Pierre. Existence and uniqueness of the solution for the bidomain model used in cardiac electrophysiology. *Nonlinear Anal. Real World Appl.*, 10(1):458–482, 2009. DOI:doi:10.1016/j.nonrwa.2007.10.007.

[4] Y. Coudière and C. Pierre. Stability and convergence of a finite volume method for two systems of reaction-diffusion equations in electro-cardiology. *Nonlinear Anal. Real World Appl.*, 7(4):916–935, 2006.

[5] A. Dervieux, D. Leservoisier, P.-L. George, and Y. Coudière. About theoretical and practical impact of mesh adaptation on approximation of functions and PDE solutions. *Internat. J. Numer. Methods Fluids*, 43(5):507–516, 2003.

[6] Y. Coudière, T. Gallouët, and R. Herbin. Discrete Sobolev inequalities and L^p error estimates for finite volume solutions of convection diffusion equations. *Math. Model. Numer. Anal.*, 35(4):767–778, 2001.

[7] Y. Coudière, J.-P. Vila, and P. Villedieu. Convergence d'un schéma volumes finis explicite en temps pour les systèmes hyperboliques linéaires symétriques en domaines bornés (convergence of a finite volume time-explicit scheme for symmetric linear hyperbolic systems on bounded domains). *C.R. Acad. Sci., Paris, Sér. I, Math.*, 331:95–100, 2000.

[8] Y. Coudière and P. Villedieu. Convergence of a finite volume scheme for the linear convection-diffusion equation on locally refined meshes. *Math. Model. Numer. Anal.*, 34(6):1109–1295, 2000.

[9] Y. Coudière, J.-P. Vila, and P. Villedieu. Convergence rate of a finite volume scheme for a two dimensional diffusion convection problem. *Math. Model. Numer. Anal.*, 33(3):493–516, 1999.

Medical Imaging Conferences

This special section gathers my contributions to collaborative works in selectives bio-imaging/bio-engineering international conferences, with publications in a major series, *Lecture notes in Computer Sciences*.

[10] Sermesant M., Konukoglu E., Delingette H., Coudière Y., Chinchapatnam P., Rhode K.S., Razavi R., and Ayache N. An anisotropic multi-front fast marching method for real-time simulation of cardiac electrophysiology. *Functional imaging and modeling of the heart. 4th international conference*, number 4466 in Lect. Notes Comput. Sci.. Springer, 2007.

[11] M. Sermesant, Y. Coudiere, V. Moreau-Villeger, K.S. Rhode, D.L. Hill, and R.S. Razavi. A fast-marching approach to cardiac electrophysiology simulation for xmr interventional imaging. *Medical image computing and computer-assisted intervention - MICCAI 2005. 8th international conference*, number 3750 in Lect. Notes Comput. Sci. Springer, 2005.

[12] M. Sermesant, Y. Coudière, H. Delingette, N. Ayache, and J.A. Désidéri. An electro-mechanical model of the heart for cardiac image analysis. In W. J. Niessen and M. A. Viergever, editors, *Medical image computing and computer-assisted intervention - MICCAI 2001. 4th international conference*, number 2208 in Lect. Notes Comput. Sci., pages 224–231. Springer, 2001.

[13] N. Ayache, D. Chapelle, F. Clément, Y. Coudière, H. Delingette, J.A. Désidéri, M. Sermesant, M. Sorine, and José M. Urquiza. Towards model-based estimation of the cardiac electro-mechanical activity from ecg signals and ultrasound images. In T. Katila, I.E. Magnin, P. Clarysse, J. Montagnat, and J. Nenonen, editors, *Functional imaging and modeling of the heart. 1st international workshop*, number 2230 in Lect. Notes Comput. Sci., pages 120–127. Springer, 2001.

International Conferences

This section collects my original contributions to international conferences in applied mathematics and also in the fields of bio-imaging/engineering ([17, 22, 23, 24]) and medecine([18, 19]).

[14] Y. Coudière and F. Hubert. A 3D discrete duality finite volume method for nonlinear elliptic equations. In *Algoritmy, Conference on Scientific Computing*, Slovakia, 2009. `http://hal.archives-ouvertes.fr/hal-00356879/fr`.

[15] Y. Coudière, C. Pierre, and R. Turpault. A 2D/3D finite volume method used to solve the bidomain equations of electrocardiology. In *Algoritmy, Conference on Scientific Computing*, Slovakia, 2009. `http://hal.archives-ouvertes.fr/hal-00357267/fr`.

[16] Y. Coudière, C. Pierre, and R. Turpault. A DDFV scheme for anisotropic and heterogeneous elliptic equations, application to a bio-mathematics problem: electrocardiogram simulation. 5th Conference on Finite volumes for complex applications, Problems and perspectives, London (UK) Wiley, 2008.

[17] M. Pop, M. Sermesant, Y. Coudière, J. Graham, M. Bronskill, A. Dick, and G. Wright. A theoretical model of ventricular reentry and its radiofrequency ablation therapy. In *2006 IEEE International Symposium on biomedical Imaging*, 2006.

[18] M. Pop, M. Sermesant, A. Dick, Graham J.J., Y. Coudière, and G.A. Wright. Aid of computer modelling to identify ventricular re-entries due to infarct scars. In *15th World Congress in Cardiac Electrophysiology and Cardiac Techniques*, volume 8. Europace, 2006. Supplement 1.

[19] M. Pop, M. Sermesant, Graham J.J., A. Dick, Y. Coudière, and G.A. Wright. Assessment of radiofrequency ablation of ventricular arrhythmias via magnetic resonance imaging and computer modelling. In *15th World Congress in Cardiac Electrophysiology and Cardiac Techniques*, volume 8. Europace, 2006. Supplement 1.

[20] Y. Coudière, C. Pierre, and R. Turpault. A finite volume method for the coupled heart-torso bidomain model in electrocardiology. In *Computational Fluid and Solid Mechanics*, 3rd MIT conference, 2005.

[21] Y. Coudière, C. Pierre, and R. Turpault. Stability and convergence of a finite volume method for a reaction-diffusion system of equations in electro-cardiology. In *Finite volumes for complex applications IV. Problems and perspectives. Papers from the 4th international conference*, pages 163–172, Hermès, 2005.

[22] M. Sermesant, O. Faris, F. Evans, E. McVeigh, Y. Coudière, H. Delingette, and N. Ayache. Preliminary validation using in vivo measures of a macroscopic electrical model of the heart. In *International Symposium on Surgery Simulation and Soft Tissue Modeling - IS4TM'03*, Lect. Notes Comput. Sci., pages 230–243. Springer, 2003.

[23] M. Sermesant, Y. Coudière, H. Delingette, and N. Ayache. Progress towards an electromechanical model of the heart for cardiac image analysis. In *IEEE International Symposium on Biomedical Imaging (ISBI'02)*, 2002.

[24] M. Sermesant, Y. Coudière, H. Delingette, N. Ayache, J. Sainte-Marie, D. Chapelle, F. Clément, and M. Sorine. Progress towards model-based estimation of the cardiac electromechanical activity from ecg signals and $4d$ images. *ESAIM, Proc.*, 12:153–161, 2002.

[25] Y. Coudière, J.P. Vila, and P. Villedieu. Convergence of the finite volumes method for friedrichs' systems on bounded domains. In *on nonlinear partial differential equations*, Besançon (France), 1999. International Conference in memory of S.N. Kruskov.

[26] Y. Coudière and P. Villedieu. Cell centered finite volume schemes for convection-diffusion problems. In *Abstracts of the Invited Lectures at the Seventh International Colloquium on Numerical Analysis*, pages 233–240, Plovdiv, Bulgaria, August 1998.

[27] Y. Coudière and P. Villedieu. Convergence rate of the finite volume time-explicit upwind scheme for the maxwell system on a bounded domain. In F. Benkhaldoum and R. Vilsmeier, editors, *Finite volumes for complex applications II. Problems and perspectives. Papers from the 2nd international conference*, pages 125–132. Hermès, 1999.

[28] Y. Coudière, J.P. Vila, and P. Villedieu. Convergence of a finite volume scheme for a diffusion convection problem. In F. Benkhaldoum and R. Vilsmeier, editors, *Finite Volumes for Complex Applications*, pages 161–168. Hermès, 1996.

Others

[29] Y. Coudière, C. Pierre, and R. Turpault. Solving the fully coupled heart and torso problems of electrocardiology with a 3D discrete duality finite volume method. *Submitted*, 2006. `http://hal.archives-ouvertes.fr/hal-00016825`.

[30] Y. Bourgault and Y. Coudière and M. Rioux. Optimal monodomain approximations of the bidomain equations. In preparation, 2009.

[31] Y. Coudière and F. Hubert. Error estimates for a 3D extension of the Discrete Duality Finite Volume scheme for nonlinear elliptic equations. In preparation, 2009.

[32] Y. Coudière. Un schéma volumes finis en dualité discrète 3D, application au système bidomaine de l'éléctrocardiologie. Journées du GDR MoMaS - VF06 : anisotropie à Porquerolles, 2006.

[33] Y. Coudière and C. Pierre. Finite volume approximation of the FitzHugh-Nagumo equations. Écoles CEA-EDF-Inria - Electromechanical behaviour of the heart: confronting models with data towards medical applications, 2004.

[34] Y. Coudière, B. Palmerio, A. Dervieux, and D. Leservoisier. Accuracy barriers in mesh adaptation. Technical report, INRIA Sophia Antipolis - SMASH, 2002. http://hal.inria.fr/inria-00072060/fr.

[35] Oniboni J. Modélisation et simulation numérique de l'influx cardiaque (modeling and numerical simulation of electric wave propagation in heart). Technical report, Inria, 2001.

[36] Y. Coudière. *Analyse de schémas volumes finis sur maillages non structurés pour des problèmes linéaires hyperboliques et elliptiques.* PhD thesis, Université Paul Sabatier, 12 janvier 1999.