IN PARTNERSHIP WITH:
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Université de Lorraine

Activity Report 2017

Project-Team SPHINX

Heterogeneous Systems: Inverse Problems, Control and Stabilization, Simulation

IN COLLABORATION WITH: Institut Elie Cartan de Lorraine (IECL)

RESEARCH CENTER
Nancy - Grand Est

THEME
Optimization and control of dynamic systems

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Project-Team SPHINX

Creation of the Team: 2015 January 01, updated into Project-Team: 2016 May 01

Keywords:

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- A6.1.1. - Continuous Modeling (PDE, ODE)
- A6.2. - Scientific Computing, Numerical Analysis & Optimization
- A6.2.1. - Numerical analysis of PDE and ODE
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Other Research Topics and Application Domains:

- B2. - Health
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- B5. - Industry of the future
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1. Personnel

Research Scientists

Takéo Takahashi [Team leader, Inria, Researcher, HDR]
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Jean-Claude Vivalda [Inria, Senior Researcher, HDR]

Faculty Members

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Thomas Chambrion [Univ de Lorraine, Associate Professor]
David Dos Santos Ferreira [Univ de Lorraine, Associate Professor]
Julien Lequeurre [Univ de Lorraine, Associate Professor]
Alexandre Munnier [Univ de Lorraine, Associate Professor]
Jean-François Scheid [Univ de Lorraine, Associate Professor, HDR]
Julie Valein [Univ de Lorraine, Associate Professor]

Post-Doctoral Fellow

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PhD Students

Boris Caudron [Thales]
Meriem Bouguezzi [CEA Saclay, from Nov 2017]
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Imem Jbili [Univ de Lorraine, from March 2017]
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Administrative Assistant

Céline Simon [Inria]

2. Overall Objectives

2.1. Overall Objectives

In this project, we investigate theoretical and numerical mathematical issues concerning heterogeneous physical systems. The heterogeneities we consider result from the fact that the studied systems involve subsystems of different physical nature. In this wide class of problems, we study two types of systems: **fluid-structure interaction systems (FSIS)** and **complex wave systems (CWS)**. In both situations, one has to develop specific methods to take the coupling between the subsystems into account.

(FSIS) Fluid-structure interaction systems appear in many applications: medicine (motion of the blood in veins and arteries), biology (animal locomotion in a fluid, such as swimming fishes or flapping birds but also locomotion of microorganisms, such as amoebas), civil engineering (design of bridges or any structure exposed to the wind or the flow of a river), naval architecture (design of boats and submarines, seeking of new propulsion systems for underwater vehicles by imitating the locomotion of aquatic animals). FSIS can be studied by modeling their motions through Partial Differential Equations (PDE) and/or Ordinary Differential Equations (ODE), as is classical in fluid mechanics or in solid mechanics. This leads to the study of difficult nonlinear free boundary problems which have constituted a rich and active domain of research over the last decades.

(CWS) Complex wave systems are involved in a large number of applications in several areas of science and engineering: medicine (breast cancer detection, kidney stone destruction, osteoporosis diagnosis, etc.), telecommunications (in urban or submarine environments, optical fibers, etc.), aeronautics (target detection, aircraft noise reduction, etc.) and, in the longer term, quantum supercomputers. **For direct problems**, most theoretical issues are now widely understood. However, substantial efforts remain to be undertaken concerning the simulation of wave propagation in complex media. Such situations include heterogeneous media with strong local variations of the physical properties (high frequency scattering, multiple scattering media) or quantum fluids (Bose-Einstein condensates). In the first case for instance, the numerical simulation of such direct problems is a hard task, as it generally requires solving ill-conditioned possibly indefinite large size problems, following from space or space-time discretizations of linear or nonlinear evolution PDE set on unbounded domains. **For inverse problems**, many questions are open at both the theoretical (identifiability, stability and robustness, etc.) and practical (reconstruction methods, approximation and convergence analysis, numerical algorithms, etc.) levels.

3. Research Program

3.1. Control and stabilization of heterogeneous systems

Fluid-Structure Interaction Systems (FSIS) are present in many physical problems and applications. Their study involves solving several challenging mathematical problems:

- **Nonlinearity:** One has to deal with a system of nonlinear PDE such as the Navier-Stokes or the Euler systems;
- **Coupling:** The corresponding equations couple two systems of different types and the methods associated with each system need to be suitably combined to solve successfully the full problem;
- **Coordinates:** The equations for the structure are classically written with Lagrangian coordinates whereas the equations for the fluid are written with Eulerian coordinates;
- **Free boundary:** The fluid domain is moving and its motion depends on the motion of the structure. The fluid domain is thus an unknown of the problem and one has to solve a free boundary problem.

In order to control such FSIS systems, one has first to analyze the corresponding system of PDE. The oldest works on FSIS go back to the pioneering contributions of Thomson, Tait and Kirchhoff in the 19th century and Lamb in the 20th century, who considered simplified models (potential fluid or Stokes system). The first mathematical studies in the case of a viscous incompressible fluid modeled by the Navier-Stokes system and a rigid body whose dynamics is modeled by Newton's laws appeared much later [93], [88], [68], and almost all mathematical results on such FSIS have been obtained in the last twenty years.

The most studied FSIS is the problem modeling a **rigid body moving into a viscous incompressible fluid** ([51], [47], [87], [57], [62], [90], [92], [76], [60]). Many other FSIS have been studied as well. Let us mention [78], [65], [61], [50], [40], [56], [41], [58] for different fluids. The case of **deformable structures** has also been considered, either for a fluid inside a moving structure (e.g. blood motion in arteries) or for a moving deformable structure immersed in a fluid (e.g. fish locomotion). The obtained coupled FSIS is a complex system and its study raises several difficulties. The main one comes from the fact that we gather two systems of different nature. Some studies have been performed for approximations of this system: [45], [40], [71], [52], [43]). Without approximations, the only known results [48], [49] is done with very strong assumptions on the regularity of the initial data. Such assumptions are not satisfactory but seem inherent to this coupling between two systems of different natures. In order to study self-propelled motions of structures in a fluid, like fish locomotion, one can assume that the **deformation of the structure is prescribed and known**, whereas its displacement remains unknown ([85]). This permits to start the mathematical study of a challenging problem: understanding the locomotion mechanism of aquatic animals. This is related to control or stabilization problems for FSIS. Some first results in this direction were obtained in [66], [42], [81].

3.2. Inverse problems for heterogeneous systems

The area of inverse problems covers a large class of theoretical and practical issues which are important in many applications (see for instance the books of Isakov [67] or Kaltenbacher, Neubauer, and Scherzer [69]). Roughly speaking, an inverse problem is a problem where one attempts to recover an unknown property of a given system from its response to an external probing signal. For systems described by evolution PDE, one can be interested in the reconstruction from partial measurements of the state (initial, final or current), the inputs (a source term, for instance) or the parameters of the model (a physical coefficient for example). For stationary or periodic problems (i.e. problems where the time dependence is given), one can be interested in determining from boundary data a local heterogeneity (shape of an obstacle, value of a physical coefficient describing the medium, etc.). Such inverse problems are known to be generally ill-posed and their study leads to investigate the following questions:

- *Uniqueness.* The question here is to know whether the measurements uniquely determine the unknown quantity to be recovered. This theoretical issue is a preliminary step in the study of any inverse problem and can be a hard task.

- *Stability.* When uniqueness is ensured, the question of stability, which is closely related to sensitivity, deserves special attention. Stability estimates provide an upper bound for the parameter error given some uncertainty on data. This issue is closely related to the so-called observability inequality in systems theory.
- *Reconstruction.* Inverse problems being usually ill-posed, one needs to develop specific reconstruction algorithms which are robust to noise, disturbances and discretization. A wide class of methods is based on optimization techniques.

We can split our research in inverse problems into two classes which both appear in FSIS and CWS:

1. **Identification for evolution PDE.**

   Driven by applications, the identification problem for systems of infinite dimension described by evolution PDE has seen in the last three decades a fast and significant growth. The unknown to be recovered can be the (initial/final) state (e.g. state estimation problems [35], [59], [63], [89] for the design of feedback controllers), an input (for instance source inverse problems [32], [44], [53]) or a parameter of the system. These problems are generally ill-posed and many regularization approaches have been developed. Among the different methods used for identification, let us mention optimization techniques ([46]), specific one-dimensional techniques (like in [36]) or observer-based methods as in [73].

   In the last few years, we have developed observers to solve initial data inverse problems for a class of linear systems of infinite dimension. Let us recall that observers, or Luenberger observers [72], have been introduced in automatic control theory to estimate the state of a dynamical system of finite dimension from the knowledge of an output (for more references, see for instance [77] or [91]). Using observers, we have proposed in [80], [64] an iterative algorithm to reconstruct initial data from partial measurements for some evolution equations.We are deepening our activities in this direction by considering more general operators or more general sources and the reconstruction of coefficients for the wave equation. In connection with this problem, we study the stability in the determination of these coefficients. To achieve this, we use geometrical optics, which is a classical albeit powerful tool to obtain quantitative stability estimates on some inverse problems with a geometrical background, see for instance [38], [37].

2. **Geometric inverse problems.**

   We investigate some geometric inverse problems that appear naturally in many applications, like medical imaging and non destructive testing. A typical problem we have in mind is the following: given a domain Ω containing an (unknown) local heterogeneity ω, we consider the boundary value problem of the form

$$\begin{cases} Lu = 0, & (\Omega \setminus \omega) \\ u = f, & (\partial\Omega) \\ Bu = 0, & (\partial\omega) \end{cases}$$

   where L is a given partial differential operator describing the physical phenomenon under consideration (typically a second order differential operator), B the (possibly unknown) operator describing the boundary condition on the boundary of the heterogeneity and f the exterior source used to probe the medium. The question is then to recover the shape of ω and/or the boundary operator B from some measurement Mu on the outer boundary $\partial\Omega$. This setting includes in particular inverse scattering problems in acoustics and electromagnetics (in this case Ω is the whole space and the data are far field measurements) and the inverse problem of detecting solids moving in a fluid. It also includes, with slight modifications, more general situations of incomplete data (i.e. measurements on part of the outer boundary) or penetrable inhomogeneities. Our approach to tackle this type of problems is based on the derivation of a series expansion of the input-to-output map of the problem (typically the Dirchlet-to-Neumann map of the problem for the Calderón problem) in terms of the size of the obstacle.

3.3. Numerical analysis and simulation of heterogeneous systems

Within the team, we have developed in the last few years numerical codes for the simulation of FSIS and CWS. We plan to continue our efforts in this direction.

- In the case of FSIS, our main objective is to provide computational tools for the scientific community, essentially to solve academic problems.
- In the case of CWS, our main objective is to build tools general enough to handle industrial problems. Our strong collaboration with Christophe Geuzaine's team in Liège (Belgium) makes this objective credible, through the combination of DDM (Domain Decomposition Methods) and parallel computing.

Below, we explain in detail the corresponding scientific program.

- **Simulation of FSIS:** In order to simulate fluid-structure systems, one has to deal with the fact that the fluid domain is moving and that the two systems for the fluid and for the structure are strongly coupled. To overcome this free boundary problem, three main families of methods are usually applied to numerically compute in an efficient way the solutions of the fluid-structure interaction systems. The first method consists in suitably displacing the mesh of the fluid domain in order to follow the displacement and the deformation of the structure. A classical method based on this idea is the A.L.E. (Arbitrary Lagrangian Eulerian) method: with such a procedure, it is possible to keep a good precision at the interface between the fluid and the structure. However, such methods are difficult to apply for large displacements (typically the motion of rigid bodies). The second family of methods consists in using a *fixed mesh* for both the fluid and the structure and to simultaneously compute the velocity field of the fluid with the displacement velocity of the structure. The presence of the structure is taken into account through the numerical scheme. Finally, the third class of methods consists in transforming the set of PDEs governing the flow into a system of integral equations set on the boundary of the immersed structure. The members of SPHINX have already worked on these three families of numerical methods for FSIS systems with rigid bodies (see e.g. [84], [70], [86], [82], [83], [74]).
- **Simulation of CWS:** Solving acoustic or electromagnetic scattering problems can become a tremendously hard task in some specific situations. In the high frequency regime (i.e. for small wavelength), acoustic (Helmholtz's equation) or electromagnetic (Maxwell's equations) scattering problems are known to be difficult to solve while being crucial for industrial applications (e.g. in aeronautics and aerospace engineering). Our particularity is to develop new numerical methods based on the hybridization of standard numerical techniques (like algebraic preconditioners, etc.) with approaches borrowed from asymptotic microlocal analysis. Most particularly, we contribute to building hybrid algebraic/analytical preconditioners and quasi-optimal Domain Decomposition Methods (DDM) [39], [54], [55] for highly indefinite linear systems. Corresponding three-dimensional solvers (like for example GetDDM) will be developed and tested on realistic configurations (e.g. submarines, complete or parts of an aircraft, etc.) provided by industrial partners (Thales, Airbus). Another situation where scattering problems can be hard to solve is the one of dense multiple (acoustic, electromagnetic or elastic) scattering media. Computing waves in such media requires us to take into account not only the interaction between the incident wave and the scatterers, but also the effects of the interactions between the scatterers themselves. When the number of scatterers is very large (and possibly at high frequency [34], [33]), specific deterministic or stochastic numerical methods and algorithms are needed. We introduce new optimized numerical methods for solving such complex configurations. Many applications are related to this problem *e.g.* for osteoporosis diagnosis where quantitative ultrasound is a recent and promising technique to detect a risk of fracture. Therefore, numerical simulation of wave propagation in multiple scattering elastic media in the high frequency regime is a very useful tool for this purpose.

4. Application Domains

4.1. Robotic swimmers

Some companies aim at building biomimetic robots that can swim in an aquarium, as toys (for instance robotswim) but also for medical objectives. The website http://www.robotic-fish.net/ presents a list of several robotic fish that have been built in the last years. Some members of our Inria Project-Team (Munnier, Scheid and Takahashi) developed a collaboration with members of the automatic control laboratory of Nancy CRAN (Daafouz, Jungers) in order to construct a swimming ball in a very viscous fluid. This ball has a macroscopic size but since the fluid is highly viscous, its motion is similar to the motion of a nanorobot. Such nanorobots could be used for medical purposes to carry some medicine or perform small surgical operations. In order to get a better understanding of such robotic swimmers, we have obtained control results via shape changes and we have developed simulation tools ([74], [85]). However, in practice the admissible deformations of the ball are limited since they are realized using piezo-electric actuators. In the future, we want to take these constraints into account by developing two approaches :

1. Solve the control problem by limiting the set of admissible deformations.
2. Find the “best” location of the actuators, in the sense of being the closest to the exact optimal control.

The main tools for this investigation are the 3D codes that we have developed for simulation of fish into a viscous incompressible fluid (SUSHI3D) or into an inviscid incompressible fluid (SOLEIL).

4.2. Aeronautics

We will develop robust and efficient solvers for problems arising in aeronautics (or aerospace) like electromagnetic compatibility and acoustic problems related to noise reduction in an aircraft. Our interest for these issues is motivated by our close contacts with companies like Airbus or Thales Systèmes Aéroportés. We will propose new applications needed by these partners and assist them in integrating these new scientific developments in their home-made solvers. In particular, in collaboration with C. Geuzaine (Université de Liège), we are building a freely available parallel solver based on Domain Decomposition Methods that can handle complex engineering simulations, in terms of geometry, discretization methods as well as physics problems, see http://onelab.info/wiki/GetDDM. Part of this development is done through the grant ANR BECASIM.

5. Highlights of the Year

5.1. Highlights of the Year

- Sphinx was evaluated in March 2017.
- A new ANR project (QUACO) has been accepted; its coordinator is Thomas Chambrion.

6. New Software and Platforms

6.1. GetDDM

KEYWORDS: Large scale - 3D - Domain decomposition - Numerical solver
FUNCTIONAL DESCRIPTION: GetDDM combines GetDP and Gmsh to solve large scale finite element problems using optimized Schwarz domain decomposition methods.

- Contact: Xavier Antoine
- URL: http://onelab.info/wiki/GetDDM

6.2. GPELab

Gross-Pitaevskii equations Matlab toolbox

KEYWORDS: 3D - Quantum chemistry - 2D
FUNCTIONAL DESCRIPTION: GPELab is a Matlab toolbox developed to help physicists for computing ground states or dynamics of quantum systems modeled by Gross-Pitaevskii equations. This toolbox allows the user to define a large range of physical problems (1d-2d-3d equations, general nonlinearities, rotation term, multi-components problems...) and proposes numerical methods that are robust and efficient.

- Contact: Xavier Antoine
- URL: http://gpelab.math.cnrs.fr/

7. New Results

7.1. Control and stabilization of heterogeneous systems

7.1.1. Analysis of heterogeneous systems

Participants: Jean-François Scheid, Takéo Takahashi.

In [12], we consider a single disk moving under the influence of a 2D viscous fluid and study the asymptotic as the size of the solid tends to zero. If the density of the solid is independent of the size, the energy equality is not sufficient to obtain a uniform estimate for the solid velocity. This is achieved thanks to the optimal $L^p - L^q$ decay estimates of the semigroup associated to the fluid-rigid body system and to a fixed point argument.

In [10], we propose a new model for the motion of a viscous incompressible fluid. More precisely, we consider the Navier-Stokes system with a boundary condition governed by the Coulomb friction law. With this boundary condition, the fluid can slip on the boundary if the tangential component of the stress tensor is too large. We prove the existence and uniqueness of a weak solution in the two-dimensional problem and the existence of at least one solution in the three-dimensional case. In [9], we consider this model with a rigid body. We prove that there exists a weak solution for the corresponding system.

In [13], we study a free boundary problem modeling the motion of a piston in a viscous gas. The gas-piston system fills a cylinder with fixed extremities, which possibly allow gas from the exterior to penetrate inside the cylinder. The gas is modeled by the 1D compressible Navier-Stokes system and the piston motion is described by the second Newton's law. We prove the existence and uniqueness of global in time strong solutions. The main novelty is that we include the case of non homogeneous boundary conditions.

In [31], we study the shape differentiability of the free-boundary 1-dimensional simplified model for a fluid-elasticity system. The full characterization of the associated material derivatives is given and the shape derivative of an energy functional has been obtained.

7.1.2. Control of heterogeneous systems

Participants: Thomas Chambrion, Alessandro Duca, Takéo Takahashi.

In [11], we consider the swimming into a stationary Navier-Stokes fluid. The swimmer is a rigid body $\mathcal{S} \subset \mathbb{R}^3$ immersed in an infinitely extended fluid. We are interested in self-propelled motions of $\mathcal{S}$ in the steady state regime of the rigid body-fluid system, assuming that the mechanism used by the body to reach such a motion is modeled through a distribution of velocities on the boundary. We show that this can be solved as a control problem.

In [16] we prove that the Kuramoto-Sivashinsky equation is locally controllable in 1D and in 2D with one boundary control. His method consists in combining several general results in order to reduce the null-controllability of this nonlinear parabolic equation to the exact controllability of a linear beam or plate system. This improves known results on the controllability of Kuramoto-Sivashinsky equation and gives a general strategy to handle the null-controllability of nonlinear parabolic systems.

The paper [21] is the result of a long term analysis about the restrictions to the controllability of bilinear systems induced by the regularity of the propagators for the bilinear Schrödinger equation. This paper comes along with its companion paper [20] which gives a detailed proof of the celebrated Ball-Marsden-Slemrod obstruction to exact controllability for bilinear systems with L^1 controls.

The paper [23] is concerned with the one dimensional bilinear Schrödinger equation in a bounded domain. In this article, we have given the first available upper bound estimates of the time needed to steer exactly the infinite square potential well from its first eigenstate to the second one.

In [22], we present an embedded automatic strategy for the control of a low consumption vehicle equipped with an "on/off" engine. The proposed strategy has been successfully implemented on the Vir'Volt prototype in official competition (European Shell Eco Marathon).

7.1.3. Stabilization of heterogeneous systems

Participants: David Dos Santos Ferreira, Takéo Takahashi, Julie Valein, Jean-Claude Vivalda.

In [8], we find, thanks to a a semiclassical approach, L^p estimates for the resolvants of the damped wave operator given on compact manifolds whose dimension is greater than 2.

In [7], we study the feedback stabilization of a system composed by an incompressible viscous fluid and a deformable structure located at the boundary of the fluid domain. We stabilize the position and the velocity of the structure and the velocity of the fluid around a stationary state by means of a Dirichlet control, localized on the exterior boundary of the fluid domain and with values in a finite dimensional space.

In [19], we study the nonlinear Korteweg-de Vries equation with boundary time-delay feedback. Under appropriate assumption on the coefficients of the feedbacks, we first prove that this nonlinear infinite dimensional system is well-posed for small initial data. The main results of our study are two theorems stating the exponential stability of the nonlinear time delay system, using two different methods: a Lyapunov functional approach and an observability inequality approach.

In [14], we generalize a formula, due to E. Sontag *et al.*, giving explicitly a continuous stabilizing feedback for systems affine in the control; more specifically for a large class of systems which depend quadratically on the control, an explicit formula for a stabilizing feedback law is given.

7.2. Inverse problems for heterogeneous systems

7.2.1. Reconstruction of coefficients and initial conditions

Participants: Karim Ramdani, Julie Valein, Jean-Claude Vivalda.

In [79], we proposed an algorithm for estimating from partial measurements the population for a linear age-structured population diffusion model. In this work, the physical parameters of the model were assumed to be known. In [29], we investigate the inverse problem of simultaneously estimating the population and the spatial diffusion coefficient for an age-structured population model. The measurement used is the time evolution of the population on a subdomain in space and age. The proposed method is based on the generalization to the infinite dimensional setting of an adaptive observer originally proposed for finite dimensional systems.

In [18], we show that, generically, a (finite dimensional) sampled system is observable provided that the number of outputs is at least equal to the number of inputs plus 2. This work complements some previous works on the subject.

7.2.2. Geometrical inverse problems

Participants: Alexandre Munnier, Karim Ramdani, Takéo Takahashi.

In [75], we proposed an explicit reconstruction formula for a two-dimensional cavity inverse problem. The proposed method was limited to the case of a single cavity due to the use of conformal mappings. In [28], we consider the case of a finite number of cavities and aim to recover the location and the shape of the cavities from the knowledge of the Dirichlet-to-Neumann (DtN) map of the problem. The proposed reconstruction method is non iterative and uses two main ingredients. First, the authors show how to compute so-called generalized Pólia-Szegö tensors (GPST) of the cavities from the DtN of the cavities. Secondly, the authors shows that the obtained shape from GPST inverse problem can be transformed into a shape from moments problem, for some particular configurations. However, numerical results suggest that the reconstruction method is efficient for arbitrary geometries.

In [15], we consider the geometrical inverse problem consisting in recovering an unknown obstacle in a viscous incompressible fluid by measurements of the Cauchy force on the exterior boundary. We deal with the case where the fluid equations are the nonstationary Stokes system and using the enclosure method, we can recover the convex hull of the obstacle and the distance from a point to the obstacle. With the same method, we can obtain the same result in the case of a linear fluid-structure system composed by a rigid body and a viscous incompressible fluid.

7.3. Numerical analysis and simulation of heterogeneous systems

Participants: Xavier Antoine, Qinglin Tang.

In [1], we propose a simple accelerated pseudo-spectral algorithm to compute the stationary states of the Gross-Piteavskii Equation (GPE) with possibly multiple components. The method is based on the adaptation of new optimization algorithms under constraints coming from mathematical imaging to the imaginary time (gradient-like) method for the GPE arising in Bose-Einstein Condensation.

In [3] we propose original efficient preconditioned conjugate gradient methods coming from molecular physics to the GPE for spectrally computing the stationary states of the GPE. The method allows a gain of a factor 100 for 3D problems with extremely large nonlinearities and fast rotations. The HPC solver is being developed.

In [17], we develop new robust and efficient algorithms for computing the dynamics of 2-components GPEs with dipolar interaction. The main particularity of the method is that high accuracy is obtained by a new FFT based evaluation of nonlocal kernels applied to the nonlinear part of the operator.

In [4], we propose an asymptotic mathematical analysis of domain decomposition techniques for solving the 1D nonlinear Schrödinger equation and GPE. The analysis uses advanced techniques related to fractional microlocal analysis for PDEs. Simulations confirm the mathematical analysis.

In [2], we extend, by some very technical mathematical analysis, approaches for the results stated in [4]. Again, numerical simulations validate the theoretical analysis.

In [5], we develop and implement in parallel simple new solvers for computing the dynamics of solutions to the Dirac equation arising in quantum physics. Numerical examples are developed to analyze the capacity of these algorithms for a parallel implementation.

In [6], we introduce the concept of Absorbing Boundary Conditions and Perfectly Matched Layers for the dynamics of nonlinear problems related to classical and relativistic quantum wave problems (Wave equation, Schrödinger equation, Dirac eqution). In particular, we show application examples and detail the methods so that they can be implemented by researchers coming for quantum physics.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

From February 2018, T. Chambrion will be the advisor of Ayoub Lasri for a PhD thesis (CIFRE label pending) on the stabilization of the Mosel river funded by *Voies Navigables de France*. This thesis is part of an international cooperation with BAW (the German counterpart of VNF, based in Karlsruhe) and Universität Stuttgart started in November 2017.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

- **Project Acronym :** iproblems
  Project Title : Inverse Problems
  Coordinator : David Dos Santos Ferreira
  Duration : 48 months (2013-2017)
  Partner: Institut Élie Cartan de Lorraine
  URL: http://www.agence-nationale-recherche.fr/Projet-ANR-13-JS01-0006
- **Project Acronym :** IFSMACS
  Project Title : Fluid-Structure Interaction: Modeling, Analysis, Control and Simulation
  Coordinator: Takéo Takahashi
  Participants: Julien Lequeurre, Alexandre Munnier, Jean-François Scheid, Takéo Takahashi
  Duration : 48 months (starting on October 1st, 2016)
  Other partners: Institut de Mathématiques de Bordeaux, Inria Paris, Institut de Mathématiques de Toulouse
  Abstract: The aim of this project is to analyze systems composed by structures immersed in a fluid. Studies of such systems can be motivated by many applications (motion of the blood in veins, fish locomotion, design of submarines, etc.) but also by the corresponding challenging mathematical problems. Among the important difficulties inherent to these systems, one can quote nonlinearity, coupling, free-boundaries. Our objectives include asymptotic analyses of FSIS, the study of controllability and stabilizability of FSIS, the understanding of locomotion of self-propelled structures and the analyze and development of numerical tools to simulate fluid-structure system.
  URL: http://ifsmacs.iecl.univ-lorraine.fr/
- Xavier Antoine is member of the project TECSER funded by the French armament procurement agency in the framework of the Specific Support for Research Works and Innovation Defense (ASTRID 2013 program) operated by the French National Research Agency.
  Project Acronym: TECSER
  Project Title : Nouvelles techniques de résolution adaptées à la simulation haute performance pour le calcul SER
  Coordinator: Stéphane Lanteri (Inria, NACHOS project-team)
  Duration: 36 months (starting on May 1st, 2014)
  Other partners: EADS (France Innovation Works Dep.), NUCLETUDES
  URL: http://www-sop.inria.fr/nachos/projects/tecser/index.php/Main/HomePage
- **Project Acronym:** BoND
  Project Title: Boundaries, Numerics and Dispersion.
  Coordinator: Sylvie Benzoni (Institut Camille Jordan, Lyon, France)
  Participant: Xavier Antoine
  Duration: 48 months (starting on October 15th, 2013)
  URL: http://bond.math.cnrs.fr

- Xavier Antoine is the local coordinator of the ANR project BECASIM.
  Project acronym: BECASIM
  Project Title: Bose-Einstein Condensates: Advanced SIMulation Deterministic and Stochastic Computational Models, HPC Implementation, Simulation of Experiments.
  Coordinator: Ionut Danaila (Université de Rouen, France)
  Participant: Xavier antoine
  Duration: 48 months (plus an extension of 12 months, until November 2017)
  Other partners: Laboratoire de Mathématiques Raphaël Salem, (Université de Rouen); Laboratoire Jacques-Louis Lions (Université Pierre et Marie Curie); Centre de Mathématiques Appliquées (Ecole Polytechnique); Centre d'Enseignement et de Recherche en Mathématiques et Calcul Scientifique (École des Ponts ParisTech); Loria; Laboratoire Paul Painlevé (Université Lille 1) et Inria-Lille Nord-Europe; Institut de Mathématiques et de Modélisation de Montpellier (Université Montpellier 2)
  URL: http://becasim.math.cnrs.fr
- **Project Acronym:** QUACO
  Project title: use of geometrical tools for the control of quantum system and application to MRI.
  Coordinator: Thomas Chambrion
  Duration: 48 months (starting January 1st 2018).
- **Project acronym:** ISDEEC
  Project title: Interaction entre Systèmes Dynamiques, Equations d'Evolution et Contrôle
  Coordinator: Romain Joly
  Participant: Julie Valein
  Other partners: Institut Fourier, Grenoble; Département de Mathématiques d'Orsay
  Duration: 36 months (2017-2020)
  URL: http://isdeec.math.cnrs.fr/

9.1.2. CNRS

Thomas Chambrion is the coordinator of the Research Project from CNRS Inphynity "DISQUO" (5300 euros, 2017).

9.2. International Initiatives

9.2.1. Participation in Other International Programs

D. Dos Santos Ferreira and J.-F. Scheid are members of the PHC Utique program ...

Program: PHC Utique

Project title: Équations aux Dérivées Partielles Déterministes et Stochastiques

Duration: January 2017-January 2020

Other partners: Laboratoire de Modélisation De´terministe et Ale´atoire (LAMDA), École Supérieure des Sciences et de la Technologie de Hammam Sousse (ESSTHS), Université de Sousse, Tunisie.

Abstract: The main objective of this project is to study some systems of Ordinary Differential Equations (ODE) and Partial Differential Equations (PDE) in a deterministic and stochastic frameworks with analytical, numerical, probabilistic or statistical methods. A typical system considered in this project is the modeling and the numerical simulations of the myocardial infarction (heart attack). This phenomenon is studied as a fluid/structure interaction type process between the blood, the cholesterol deposit along the walls of an artery and the rupture of the atherosclerotic plaque formed by the cholesterol.

This is a project for a French-Tunisian collaboration and it involved a PhD thesis co-advised by J.-F. Scheid.

J. Valein is member of the project ICoPS:

Program: MATH-AmSud

Project acronym: ICoPS

Project title: Inverse and control problems for physical systems

Duration: 01/2017-12/2018

Coordinators: Alberto Mercado (Valparaíso, Chile), Emmanuelle Crépeau (Versailles), Daniel Alfaro (Rio de Janeiro, Brasil), Ivonne Rivas (Colombia)

Other partners: Centre Automatique et Systèmes (École des Mines de Paris), LAAS (Toulouse), Instituto de Matemática, Estadística e Física (Universidade Federal do Rio Grande do Sul, Brasil), Departamento de Matemáticas y Estadística, (Universidad Icesi, Pance, Cali, Colombia)

Abstract: We propose to study well-posedness, control properties, and coefficient inverse problems for partial differential equations appearing in models for several phenomena. We intend to study the inverse problems of recovering some coefficients in the previously mentioned equations, and also in nonlinear dispersive waves on trees, which appears for instance in model for the cardiovascular system. We intend to study numerical approximations, using numerical schemes like Galerkin, colocation, finite difference, among others. Finally, this proposal includes the determination of the reachable states in a control problem of KdV equation.

9.3. International Research Visitors

J.-F. Scheid has been visitor of the l'ESSTHS (Hammam-Sousse, Tunisia) for two weeks (work related to the thesis of Imen JBILI) and course on numerical methods for the Navier-Stokes equations).

9.3.1. Visits of International Scientists

Sorin Micu (University of Craiova) was an invited professor (University of Lorraine) from 12/01/2017 to 12/02/2017.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. Member of the Organizing Committees

K. Ramdani was member of the Organizing Committee of the Conference “Accès ouvert : rêve ou réalité ?” (CIRM, October 2017) organized by the RNBM (Réseau National des Bibliothèques de Mathématiques). During this conference, two days were more especially scientists-oriented and devoted to new models of publication, and more especially open access journals (for more details, see: http://www.rnbm.org/cirm-2017).

10.1.1.2. General chair, Scientific chair

T. Takahashi co-organized a conference, in the framework of the ANR's project IFSMACS, at the Institut de Mathématiques de Bordeaux from the 2nd to the 5th of October 2017 (see https://indico.math.cnrs.fr/event/1367/).

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

J.-C. Vivalda is a member of the editorial board of the “Journal of Dynamical and Control Systems”. David Dos Santos Ferreira is member of the editorial board of “Mathematical Control and Related Fields”.

10.1.2.2. Reviewer - Reviewing Activities

J.-F. Scheid is reviewer for the “Applied Mathematics and Optimization” journal.

J.-C. Vivalda is reviewer for the “Mathematical reviews”.

10.1.3. Invited Talks

- T. Chambrion has been invited to the “Recife Workshop on Control and Stabilization of PDEs” held from 13 to 17 February 2017 in Recife (Brasil). See https://sites.google.com/site/recontrolpde/.
- T. Chambrion has been invited to the seminar of Université de Nice (analysis) in November 2017 and Strasbourg (December 2017).
- T. Takahashi was an invited speaker at the conference CDPS 2017 in Bordeaux (see https://indico.math.cnrs.fr/event/1363/).

10.1.4. Leadership within the Scientific Community

T. Chambrion has been a co-animator (with F. Di Meglio) of the GT EDP in GDR MACS until the redesign of the working groups in November 2017.

D. Dos Santos Ferreira is one of the coordinators of the GDR “Analyse des EDP”.

10.1.5. Research Administration

- Karim Ramdani was deputy delegate for scientific affairs of the Inria Nancy research center until August 31, 2017.
- Karim Ramdani is member of the board of the RNBM (Réseau National des Bibliothèques de Mathématiques) and is in charge with Benoît Kloeckner of Open Access issues.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

With the exception of K. Ramdani, T. Takahashi and J.-C. Vivalda, SPHINX members have teaching obligations at "Universite´ de Lorraine" and are teaching at least 192 hours each year. They teach mathematics at different level (Licence, Master, Engineering school). Many of them have pedagogical responsibilities.

10.2.2. Supervision

PhD in progress: Mohamed ID SAID, Embedded automatic control with limited computational resources, from October 2017, supervisors: T. Chambrion and G. Millerioux;

PhD in progress: Meriem BOUGUEZZI, Reaction-diffusion system for the modeling of a corrosion phenomena, from november 2017, J.-F. Scheid (co-supervisor);

PhD in progress: Imem JBIL, Myocardial infarction as a fluid-structure system : modeling and simulations, from mars 2017, J.-F. Scheid (co-supervisor);

PhD in progress: Imene DJEBOUR, Control and inverse problems on fluid-structure interaction systems, from November 2017, supervisor : Takahashi

PhD in progress: Benjamin Obando, Mathematical study of the dynamics of heterogeneous granular flows, from August 2015, supervisors : Takahashi and San Martín (Universidad de Chile)

10.2.3. Juries

David Dos Santos Ferreira reviewed the application of Joonas Ilmavirta for position of “docent” at Helsinki University. He was also a member of the HDR (Accreditation to Supervise Research) thesis jury of Yavar Kian (defended in November 2017).

11. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

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