Activity Report 2019

Team REO

Numerical simulation of biological flows

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Paris

THEME
Modeling and Control for Life Sciences

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Team REO

Creation of the Team: 2019 January 01

Keywords:

Computer Science and Digital Science:

A6.1.1. - Continuous Modeling (PDE, ODE)
A6.1.5. - Multiphysics modeling
A6.3.2. - Data assimilation
A6.5.2. - Fluid mechanics

Other Research Topics and Application Domains:

B2.2. - Physiology and diseases
B2.4.3. - Surgery

1. Team, Visitors, External Collaborators

Research Scientists

Irene Vignon-Clementel [Team leader, Inria, Senior Researcher, HDR]
Miguel Angel Fernandez Varela [Team leader, Inria, Senior Researcher, until May 2019, HDR]
Céline Grandmont [Inria, Senior Researcher, until May 2019, HDR]
Damiano Lombardi [Inria, Researcher, until May 2019]
Marina Vidrascu [Inria, Emeritus, until May 2019, HDR]

Faculty Members

Laurent Boudin [Univ Pierre et Marie Curie, Associate Professor, until May 2019]
Muriel Boulakia [Univ Pierre et Marie Curie, Associate Professor, until May 2019]

Post-Doctoral Fellow

Jean Jerome Casanova [Inria, Post-Doctoral Fellow, until May 2019]

PhD Students

Nicolas Golse [APHP-Inria, PhD Student]
Ludovic Boilevin-Kayl [Inria, PhD Student, until May 2019]
Chen-Yu Chiang [Univ Pierre et Marie Curie, PhD Student, until Jan 2019]
Felipe Galarce Marin [Inria, PhD Student, until May 2019]
Fannie Gerosa [Inria, PhD Student, until May 2019]
Fabien Raphel [Inria, PhD Student, from Apr 2019 until May 2019]

Technical staff

Daniele Carlo Corti [Inria, Engineer, until May 2019]
Fabien Raphel [Inria, Engineer, until Mar 2019]

Interns and Apprentices

Quentin Nicolas [Inria, from Mar 2019 until Jul 2019]
Nour Bou Saleh [Inria-Inserm, until Nov 2019]
Lazaros Papamanolis [Centrale-Supélec]
Marguerite Champion [until Feb 2019]
Justine Dorsz [Inria, until Jan 2019]
Valeria Secchi [Inria, from Apr 2019 until May 2019]
Colette Voisembert [Inria, from Apr 2019 until May 2019]

Administrative Assistants

Laurence Bourcier [Inria, Administrative Assistant]

Julien Guieu [Inria, Administrative Assistant, from Apr 2019]
Maryse Desnous [Inria, Administrative Assistant, until Apr 2019]

Visiting Scientists

Damien Dousse [Inserm, until Nov 2019]
David Sampedro Puente [from Feb 2019 until Apr 2019]

2. Overall Objectives

2.1. Overall Objectives

REO is a joint project-team of the Inria Research Center of Paris and the Jacques-Louis Lions Laboratory (LJLL) of the Pierre and Marie Curie University (Sorbonne Universié, UPMC Paris 6) and CNRS (UMR7598). Its main objectives are:

- the modeling of blood flow in large vessels, air flow in the respiratory tract, and the cardiac electrophysiology;
- the design and the analysis of efficient and robust numerical methods for these problems;
- the development of numerical software to assist medical decisions and to contribute to the design of medical devices.

REO put a strong effort in working with real data, coming either from clinicians or industrial partners. The development of methods for the interaction of data and simulation is therefore an important aspect of the activity of the team.
Most of the REO members are now in the project-team COMMEDIA since June 2019. The team description (research program and application domains) remains the original REO one. The other sections, and in particular the new results only reflect the remaining members. The articles of the year 2019 are the ones of REO members that did not move to COMMEDIA.

3. Research Program

3.1. Multiphysics modeling

In large vessels and in large bronchi, blood and air flows are generally supposed to be governed by the incompressible Navier-Stokes equations. Indeed in large arteries, blood can be supposed to be Newtonian, and at rest air can be modeled as an incompressible fluid. The cornerstone of the simulations is therefore a Navier-Stokes solver. But other physical features have also to be taken into account in simulations of biological flows, in particular fluid-structure interaction in large vessels and transport of sprays, particles or chemical species.

3.1.1. Fluid-structure interaction

Fluid-structure coupling occurs both in the respiratory and in the circulatory systems. We focus mainly on blood flows since our work is more advanced in this field. But the methods developed for blood flows could be also applied to the respiratory system.

Here “fluid-structure interaction” means a coupling between the 3D Navier-Stokes equations and a 3D (possibly thin) structure in large displacements.

The numerical simulations of the interaction between the artery wall and the blood flows raise many issues: (1) the displacement of the wall cannot be supposed to be infinitesimal, geometrical nonlinearities are therefore present in the structure and the fluid problem have to be solved on a moving domain (2) the densities of the artery walls and the blood being close, the coupling is strong and has to be tackled very carefully to avoid numerical instabilities, (3) “naive” boundary conditions on the artificial boundaries induce spurious reflection phenomena.

Simulation of valves, either at the outflow of the cardiac chambers or in veins, is another example of difficult fluid-structure problems arising in blood flows. In addition, very large displacements and changes of topology (contact problems) have to be handled in those cases.

Due to stability reasons, it seems impossible to successfully apply in hemodynamics the explicit coupling schemes used in other fluid-structure problems, like aeroelasticity. As a result, fluid-structure interaction in biological flows raise new challenging issues in scientific computing and numerical analysis : new schemes have to be developed and analyzed.

We have proposed and analyzed over the last few years several efficient fluid-structure interaction algorithms. This topic remains very active. We are now using these algorithms to address inverse problems in blood flows to make patient specific simulations (for example, estimation of artery wall stiffness from medical imaging).

3.1.2. Aerosol

Complex two-phase fluids can be modeled in many different ways. Eulerian models describe both phases by physical quantities such as the density, velocity or energy of each phase. In the mixed fluid-kinetic models, the biphasic fluid has one dispersed phase, which is constituted by a spray of droplets, with a possibly variable size, and a continuous classical fluid.

This type of model was first introduced by Williams [36] in the frame of combustion. It was later used to develop the Kiva code [26] at the Los Alamos National Laboratory, or the Hesione code [31], for example. It has a wide range of applications, besides the nuclear setting: diesel engines, rocket engines [29], therapeutic sprays, *etc.* One of the interests of such a model is that various phenomena on the droplets can be taken into account with an accurate precision: collision, breakups, coagulation, vaporization, chemical reactions, *etc.*, at the level of the droplets.

The model usually consists in coupling a kinetic equation, that describes the spray through a probability density function, and classical fluid equations (typically Navier-Stokes). The numerical solution of this system relies on the coupling of a method for the fluid equations (for instance, a finite volume method) with a method fitted to the spray (particle method, Monte Carlo).

We are mainly interested in modeling therapeutic sprays either for local or general treatments. The study of the underlying kinetic equations should lead us to a global model of the ambient fluid and the droplets, with some mathematical significance. Well-chosen numerical methods can give some tracks on the solutions behavior and help to fit the physical parameters which appear in the models.

3.2. Multiscale modeling

Multiscale modeling is a necessary step for blood and respiratory flows. In this section, we focus on blood flows. Nevertheless, similar investigations are currently carried out on respiratory flows.

3.2.1. Arterial tree modeling

Problems arising in the numerical modeling of the human cardiovascular system often require an accurate description of the flow in a specific sensible subregion (carotid bifurcation, stented artery, *etc.*). The description of such local phenomena is better addressed by means of three-dimensional (3D) simulations, based on the numerical approximation of the incompressible Navier-Stokes equations, possibly accounting for compliant (moving) boundaries. These simulations require the specification of boundary data on artificial boundaries that have to be introduced to delimit the vascular district under study. The definition of such boundary conditions is critical and, in fact, influenced by the global systemic dynamics. Whenever the boundary data is not available from accurate measurements, a proper boundary condition requires a mathematical description of the action of the reminder of the circulatory system on the local district. From the computational point of view, it is not affordable to describe the whole circulatory system keeping the same level of detail. Therefore, this mathematical description relies on simpler models, leading to the concept of *geometrical multiscale* modeling of the circulation [32]. The underlying idea consists in coupling different models (3D, 1D or 0D) with a decreasing level of accuracy, which is compensated by their decreasing level of computational complexity.

The research on this topic aims at providing a correct methodology and a mathematical and numerical framework for the simulation of blood flow in the whole cardiovascular system by means of a geometric multiscale approach. In particular, one of the main issues will be the definition of stable coupling strategies between 3D and reduced order models.

To model the arterial tree, a standard way consists of imposing a pressure or a flow rate at the inlet of the aorta, *i.e.* at the network entry. This strategy does not allow to describe important features as the overload in the heart caused by backward traveling waves. Indeed imposing a boundary condition at the beginning of the aorta artificially disturbs physiological pressure waves going from the arterial tree to the heart. The only way to catch this physiological behavior is to couple the arteries with a model of heart, or at least a model of left ventricle.

A constitutive law for the myocardium, controlled by an electrical command, has been developed in the CardioSense3D project [1]. One of our objectives is to couple artery models with this heart model.

A long term goal is to achieve 3D simulations of a system including heart and arteries. One of the difficulties of this very challenging task is to model the cardiac valves. To this purpose, we investigate a mix of arbitrary Lagrangian Eulerian and fictitious domain approaches or x-fem strategies, or simplified valve models based on an immersed surface strategy.

3.2.2. Heart perfusion modeling

The heart is the organ that regulates, through its periodical contraction, the distribution of oxygenated blood in human vessels in order to nourish the different parts of the body. The heart needs its own supply of blood to work. The coronary arteries are the vessels that accomplish this task. The phenomenon by which blood reaches myocardial heart tissue starting from the blood vessels is called in medicine perfusion. The analysis of heart perfusion is an interesting and challenging problem. Our aim is to perform a three-dimensional dynamical numerical simulation of perfusion in the beating heart, in order to better understand the phenomena linked to perfusion. In particular the role of the ventricle contraction on the perfusion of the heart is investigated as well as the influence of blood on the solid mechanics of the ventricle. Heart perfusion in fact implies the interaction between heart muscle and blood vessels, in a sponge-like material that contracts at every heartbeat via the myocardium fibers.
Despite recent advances on the anatomical description and measurements of the coronary tree and on the corresponding physiological, physical and numerical modeling aspects, the complete modeling and simulation of blood flows inside the large and the many small vessels feeding the heart is still out of reach. Therefore, in order to model blood perfusion in the cardiac tissue, we must limit the description of the detailed flows at a given space scale, and simplify the modeling of the smaller scale flows by aggregating these phenomena into macroscopic quantities, by some kind of "homogenization" procedure. To that purpose, the modeling of the fluid-solid coupling within the framework of porous media appears appropriate.
Poromechanics is a simplified mixture theory where a complex fluid-structure interaction problem is replaced by a superposition of both components, each of them representing a fraction of the complete material at every point. It originally emerged in soils mechanics with the work of Terzaghi [35], and Biot [27] later gave a description of the mechanical behavior of a porous medium using an elastic formulation for the solid matrix, and Darcy's law for the fluid flow through the matrix. Finite strain poroelastic models have been proposed (see references in [28]), albeit with *ad hoc* formulations for which compatibility with thermodynamics laws and incompressibility conditions is not established.

3.2.3. Tumor and vascularization

The same way the myocardium needs to be perfused for the heart to beat, when it has reached a certain size, tumor tissue needs to be perfused by enough blood to grow. It thus triggers the creation of new blood vessels (angiogenesis) to continue to grow. The interaction of tumor and its micro-environment is an active field of research. One of the challenges is that phenomena (tumor cell proliferation and death, blood vessel adaptation, nutrient transport and diffusion, etc) occur at different scales. A multi-scale approach is thus being developed to tackle this issue. The long term objective is to predict the efficiency of drugs and optimize therapy of cancer.

[1] http://www-sop.inria.fr/CardioSense3D/

3.2.4. Respiratory tract modeling

We aim at developing a multiscale model of the respiratory tract. Intraprenchymal airways distal from generation 7 of the tracheabronchial tree (TBT), which cannot be visualized by common medical imaging techniques, are modeled either by a single simple model or by a model set according to their order in TBT. The single model is based on straight pipe fully developed flow (Poiseuille flow in steady regimes) with given alveolar pressure at the end of each compartment. It will provide boundary conditions at the bronchial ends of 3D TBT reconstructed from imaging data. The model set includes three serial models. The generation down to the pulmonary lobule will be modeled by reduced basis elements. The lobular airways will be represented by a fractal homogenization approach. The alveoli, which are the gas exchange loci between blood and inhaled air, inflating during inspiration and deflating during expiration, will be described by multiphysics homogenization.

4. Application Domains

4.1. Blood flows

Cardiovascular diseases like atherosclerosis or aneurysms are a major cause of mortality. It is generally admitted that a better knowledge of local flow patterns could improve the treatment of these pathologies (although many other biophysical phenomena obviously take place in the development of such diseases). In particular, it has been known for years that the association of low wall shear stress and high oscillatory shear index give relevant indications to localize possible zones of atherosclerosis. It is also known that medical devices (graft or stent) perturb blood flows and may create local stresses favorable with atherogenesis. Numerical simulations of blood flows can give access to this local quantities and may therefore help to design new medical devices with less negative impacts. In the case of aneurysms, numerical simulations may help to predict possible zones of rupture and could therefore give a guide for treatment planning.

In clinical routine, many indices are used for diagnosis. For example, the size of a stenosis is estimated by a few measures of flow rate around the stenosis and by application of simple fluid mechanics rules. In some situations, for example in the case a sub-valvular stenosis, it is known that such indices often give false estimations. Numerical simulations may give indications to define new indices, simple enough to be used in clinical exams, but more precise than those currently used.

It is well-known that the arterial circulation and the heart (or more specifically the left ventricle) are strongly coupled. Modifications of arterial walls or blood flows may indeed affect the mechanical properties of the left ventricle. Numerical simulations of the arterial tree coupled to the heart model could shed light on this complex relationship.

One of the goals of the REO team is to provide various models and simulation tools of the cardiovascular system. The scaling of these models will be adapted to the application in mind: low resolution for modeling the global circulation, high resolution for modeling a small portion of vessel.

4.2. Respiratory tracts

Breathing, or “external” respiration (“internal” respiration corresponds to cellular respiration) involves gas transport though the respiratory tract with its visible ends, nose and mouth. Air streams then from the pharynx down to the trachea. Food and drink entry into the trachea is usually prevented by the larynx structure (epiglottis). The trachea extends from the neck into the thorax, where it divides into right and left main bronchi, which enter the corresponding lungs (the left being smaller to accommodate the heart). Inhaled air is then convected in the bronchus tree which ends in alveoli, where gaseous exchange occurs. Surfactant reduces the surface tension on the alveolus wall, allowing them to expand. Gaseous exchange relies on simple diffusion on a large surface area over a short path between the alveolus and the blood capillary under concentration gradients between alveolar air and blood. The lungs are divided into lobes (three on the right, two on the left) supplied by lobar bronchi. Each lobe of the lung is further divided into segments (ten segments of the right lung and eight of the left). Inhaled air contains dust and debris, which must be filtered, if possible, before they reach the alveoli. The tracheobronchial tree is lined by a layer of sticky mucus, secreted by the epithelium. Particles which hit the side wall of the tract are trapped in this mucus. Cilia on the epithelial cells move the mucous continually towards the nose and mouth.

Each lung is enclosed in a space bounded below by the diaphragm and laterally by the chest wall and the mediastinum. The air movement is achieved by alternately increasing and decreasing the chest pressure (and volume). When the airspace transmural pressure rises, air is sucked in. When it decreases, airspaces collapse and air is expelled. Each lung is surrounded by a pleural cavity, except at its hilum where the inner pleura give birth to the outer pleura. The pleural layers slide over each other. The tidal volume is nearly equal to 500 ml.

The lungs may fail to maintain an adequate supply of air. In premature infants surfactant is not yet active. Accidental inhalation of liquid or solid and airway infection may occur. Chronic obstructive lung diseases and lung cancers are frequent pathologies and among the three first death causes in France.

One of the goals of REO team in the ventilation field is to visualize the airways (virtual endoscopy) and simulate flow in image-based 3D models of the upper airways (nose, pharynx, larynx) and the first generations of the tracheobronchial tree (trachea is generation 0), whereas simple models of the small bronchi and alveoli are used (reduced-basis element method, fractal homogenization, multiphysics homogenization, lumped parameter models), in order to provide the flow distribution within the lung segments.

4.3. Cardiac electrophysiology

The purpose is to simulate the propagation of the action potential in the heart. A lot of works has already been devoted to this topic in the literature (see *e.g.* [30], [34], [33] and the references therein), nevertheless there are only very few studies showing realistic electrocardiograms obtained from partial differential equations models. Our goal is to find a compromise between two opposite requirements: on the one hand, we want to use predictive models, and therefore models based on physiology, on the other hand, we want to use models simple enough to be parametrized (in view of patient-specific simulations). One of the goal is to use our ECG simulator to address the inverse problem of electrocardiology. In collaboration with the Macs/M3disym project-team, we are interested in the electromechanical coupling in the myocardium. We are also interested in various clinical and industrial issues related to cardiac electrophysiology, in particular the simulation of experimental measurement of the field potential of cardiac stem cells in multi-electrode arrays.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

ERC consolidator grant MoDeLLiver (I Vignon-Clementel).

6. New Results

6.1. Numerical methods for fluid mechanics and application to blood flows

Participants: Irene Vignon-Clementel

If abdominal aortic aneurysms (AAA) are known to be associated with altered morphology and blood flow, intraluminal thrombus deposit and clinical symptoms, the growth mechanisms are yet to be fully understood. In this retrospective longitudinal study of 138 scans, morphological analysis and blood flow simulations for 32 patients with clinically diagnosed AAAs and several follow-up CT-scans, are performed and compared to 9 control subjects [21]. Local correlations between hemodynamic metrics and AAA growth are also explored. Finally, high-risk predictors trained with successively clinical, morphological, hemodynamic and all data, and their link to the AAA evolution are built from supervise learning.

In this paper [19], we perform a verification study of the Coupled-Momentum Method (CMM), a 3D fluid-structure interaction (FSI) model which uses a thin linear elastic membrane and linear kinematics to describe the mechanical behavior of the vessel wall. The verification of this model is done using Womersley's deformable wall analytical solution for pulsatile flow in a semi-infinite cylindrical vessel. This solution is, under certain premises, the analytical solution of the CMM and can thus be used for model verification. For the numerical solution, we employ an impedance boundary condition to define a reflection-free outflow boundary condition and thus mimic the physics of the analytical solution, which is defined on a semi-infinite domain. We first provide a rigorous derivation of Womersley's deformable wall theory via scale analysis. We then illustrate different characteristics of the analytical solution and verification tests comparing the CMM with Womersley's theory.

Superior cavopulmonary circulation can be achieved by either the Hemi-Fontan or Bidirectional Glenn connection. Debate remains as to which results in best hemodynamic results. In [22], adopting patient-specific multiscale computational modeling, we examined both the local dynamics and global physiology to determine if surgical choice can lead to different hemodynamic outcomes.

6.2. Liver biomedical research

Participants: Irene Vignon-Clementel, Nicolas Golse

Nicolas Golse, as part of his medical activity has published 7 articles in 2019 that are not reported here.

The hepatic volume gain following resection is essential for clinical recovery. Previous studies have focused on cellular regeneration. In [13], the study aims to explore the rate of hepatic regeneration of the porcine liver following major resection, highlighting estimates of the early microarchitectural changes that occur during the cellular regeneration. Nineteen large white pigs had 75% resection with serial measurements of the hepatic volume, density, blood flow, and architectural changes that are analyzed at different days to highlight differences pre-resection and in the days following resection.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

Participants: Lazaros Papamanolis, Irene Vignon-Clementel [local coordinator].

Contract with ESIEE (H. Talbot, L. Najman) for collaboration with the Heartflow company.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

Irene Vignon Clementel is a member of the project iLite (09/16-10/21), RHU-santé grant, a large French hospital-medical research consortium that aims at developing innovations for liver and tissue engineering (Inria PI: Dirk Drasdo).

8.1.2. APHP-Inria collaboration

Participants: Nour Bou Saleh, Quentin Nicolas, Nicolas Golse, Irene Vignon-Clementel [local coordinator].

Collaboration with Eric Vibert (APHP - Inserm U1193) for cosupervision of surgery interns (N. Bousaleh, D. Dousse) and engineering intern (Q Nicolas) in the context of the APHP-Inria PhD of N. Golse, on liver modeling and ICG fluorescence.

8.2. European Initiatives

8.2.1. Collaborations in European Programs, Except FP7 & H2020

SimInhale COST Action MP1404, a pan-European network of experts in the field of inhaled medicine, coordinated by Prof. Stavros Kassinos, end: 2019 (http://www.siminhale-cost.eu).

8.3. International Initiatives

8.3.1. Inria International Partners

8.3.1.1. Informal International Partners

Collaboration with :

- Prof. Pal Dag Line from U. of Oslo, Oslo hospital U. with E. Vibert (APHP, Inserm) - N. Golse, I. Vignon-Clementel
- CHUM Centre Hospitalier de l'Université de Montreal (G Soulez and colleagues) - F. Joly (Inria), I. Vignon-Clementel

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

9.1.1.1. General Chair, Scientific Chair

I. Vignon-Clementel: Co-chair of the international conference VPH2020

9.1.1.2. Member of the Organizing Committees

Irene Vignon-Clementel: session to foster collaboration between scientists and medical doctors at the Inria/CentraleSupelec/Ap-Hp meeting, March 28th, Palaiseau, France

9.1.2. Scientific Events: Selection

9.1.2.1. Member of the Conference Program Committees

- I. Vignon-Clementel
  - Programme committee member, Computational and Mathematical Biomedical Engineering Conference
  - Conference steering committee, International Conference on Engineering Frontiers in Pediatric and Congenital Heart Disease

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

Irene Vignon-Clementel: Associate Editor of the International Journal for Numerical Methods in Biomedical Engineering

9.1.3.2. Reviewer - Reviewing Activities

Irene Vignon-Clementel for several journals such as Annals Biomed Eng, BMMB, Med. engineering &Physics.

9.1.4. Conferences and seminars

- Nicolas Golse
  - talk, 15th French congress of hepato-biliary surgery (ACHBT-SFCD), Hotel Newport Bay, Paris, 27-29 Novembre 2019
  - As part of his clinical research, N. Golse presented 7 conference talks and 5 posters
- Nour Bou Saleh
  - poster: 15th French congress of hepato-biliary surgery (ACHBT-SFCD), Hotel Newport Bay, Paris, 27-29 Novembre 2019
- Florian Joly (supported by Reo)
  - talk, ESB2019, European Society of Biomechanics Conference, July 7-10 2019, Vienna, Austria
  - talk, SB2019, Congress of the French society of biomechanics October 28-30 2019, Poitiers, France
- Irene Vignon-Clementel
  - Invited talk, Day on AI and health, School of medicine, U. Paris-Saclay, Nov 25th, Kremlin-Bicetre, France
  - Invited talk, National conference of Biomechanics, Oct 28-30, Poitiers, France
  - Round table on Healthcare 4.0, IMT, Oct 15th, St Etienne, France
  - Seminar, U. of Tokyo, June 13th, Tokyo, Japan
  - Keynote speaker, CMBE conference, June 10th-12th, Tohoku University, Sendai City, Japan
  - Keynote speaker, FIMH, June 6-8th, Bordeaux, France
  - Invited talk, International Conference on Engineering Frontiers in Pediatric and Congenital Heart Disease, May 9th-11th, Philadelphia, USA

9.1.5. Leadership within the Scientific Community

Irene Vignon-Clementel: VPHi board meeting, Oct 4th, Paris, France

9.1.6. Scientific Expertise

Irene Vignon-Clementel: Reviewer for several institutions: Helmholtz Institute (Germany), Israeli Science Foundation, Medical research council (UK), Heart research (UK)

9.1.7. Research Administration

- I. Vignon-Clementel
  - Working group to foster innovation for the Inserm strategic plan
  - Technology grant committee (Commission de développement technologique), Inria Paris center
  - Committee member for PhD students at Inria - Commission consultative des doctorants
  - Mediator between PhD students and their supervisors for Inria Paris

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence:
Irene Vignon-Clementel

- Numerical Methods for Ordinary Differential Equations, 24h ETD, L3, UPMC (2nd semester 2018-2019)
- Invited lecture as part of the undergraduate continuum mechanics class at AgroParisTech (engineering school), France

Master:

- Irene Vignon-Clementel
  - Fall school on Ventilation and Music, Cargèse, France (2h30 EDT)
  - MEC 550 - Biofluid Mechanics and Mass Transport, Ecole Polytechnique (engineering school), France (1h30 EDT)
  - Doctoral school cours Innovations thérapeutiques: du fondamental à l'appliqué, bioengineering module at ENS Cachan, France (1h30 EDT)
  - Master 2 Sciences Chirurgicales de l'Université Paris Sud, France (1h30 EDT)
- Nicolas Golse
  - Master 1 Sciences, Techniques et Santé, Faculté Médecine Kremlin Bicêtre (4.5h EDT)

University diploma (DU)

Nicolas Golse:

- DU of hepatobiliary and pancreatic surgery, 6 sessions (9h EDT)

9.2.2. Supervision

PhD in progress : Nicolas Golse, Apports de la modélisation anatomique et hémodynamique du foie dans l'anticipation, la réalisation et l'enseignement de la chirurgie hépatique, since 10/2016, co-directed by Eric Vibert, Irene Vignon-Clementel, Stephane Cotin

Defended PhD: Chen-Yu Chiang, Transport in biological systems. Monolithic method for fluid-structure interaction, Sorbonne U., 11 January 2019, co-directed by Marc Thiriet, Olivier Pironneau and Toni Sheu (National Taiwan U)

9.2.3. Juries

Irene Vignon-Clementel

- Referee for the PhD defense of Miguel Veira, KCL, London, UK, June 18th
- Jury for research projects (undergraduates), CentraleSupelec, June 4th & Nov 4th & 6th
- Hiring committee for engineer position, U. of Bordeaux, France, May 5th
- Jury member (invited), PhD defense of F. Joly, CHUM, Canada, April 15th
- Referee for the PhD defense of Mathias Braun, U. of Bordeaux, France, April 4th
- President of the jury for the HDR of Paul VanLiedekerke, Sorbonne U., France, March 26th

9.3. Popularization

9.3.1. Interventions

- N Golse (MD)
  - conference at Ecole des Mines, 14th October 2019, "Healthcare simulation"
- Irene Vignon-Clementel
  - High school forum on scientific career, 7th December, Lycee Corneille, La Celle St Cloud
  - Junior high school intervention 'women in engineering', 22nd February, Ville d'Avray
  - High school forum on scientific career, 19th January, Lycee Corneille, La Celle St Cloud
  - High school intervention, 15th January, Blanche de Castille, Le Chesnay

9.3.2. Internal action

Interviews of Irene Vignon-Clementel by journalist for Inria, 13th March and 25th Nov (see Inria website articles)

10. Bibliography

Major publications by the team in recent years

[1] L. BOUDIN, L. DESVILLETTES, C. GRANDMONT, A. MOUSSA. *Global existence of solutions for the coupled Vlasov and Navier-Stokes equations*, in "Differential and integral equations", November 2009, vol. 22, n° 11-12, pp. 1247-1271, https://hal.archives-ouvertes.fr/hal-00331895

[2] L. BOUDIN, B. GREC, F. SALVARANI. *A mathematical and numerical analysis of the Maxwell-Stefan diffusion equations*, in "Discrete and Continuous Dynamical Systems - Series B", 2012, vol. 17, n° 5, pp. 1427-1440 [*DOI :* 10.3934/DCDSB.2012.17.1427], https://hal.archives-ouvertes.fr/hal-00490511

[3] M. BOULAKIA, S. CAZEAU, M. A. FERNÁNDEZ, J.-F. GERBEAU, N. ZEMZEMI. *Mathematical Modeling of Electrocardiograms: A Numerical Study*, in "Annals of Biomedical Engineering", 2010, vol. 38, n° 3, pp. 1071-1097 [*DOI :* 10.1007/S10439-009-9873-0], https://hal.inria.fr/inria-00400490

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