



IN PARTNERSHIP WITH:  
**Université des sciences et  
technologies de Lille (Lille 1)**

Activity Report 2013

## **Project-Team SHACRA**

Simulation in Healthcare using Computer  
Research Advances

IN COLLABORATION WITH: Laboratoire d'informatique fondamentale de Lille (LIFL)

RESEARCH CENTERS  
**Lille - Nord Europe**  
**Nancy - Grand Est**

THEME  
**Computational Neuroscience and  
Medicine**



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## Project-Team SHACRA

**Keywords:** Simulation, Image Guided Intervention, Augmented Reality, Virtual Physiology, Finite Elements, High Performance Computing

*Creation of the Project-Team:* 2012 January 01.

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### 2. Overall Objectives

#### 2.1. Team Overview

The medical field has been a domain of application for computer science for more than a decade, and several tools, such as image processing, are now an integral part of modern medicine. Large-scale projects such as the Virtual Physiological Human promoted by the European Commission or the Virtual Physiological Patient Project launched in 2012 by the FDA (US Food and Drug Administration) aim at providing comprehensive, virtual and validated computer models of human anatomy and pathologies. National initiatives such as the IHU in Strasbourg promote the use of computer simulation in a clinical context. We strongly believe that the (real-time) simulation of the behavior of anatomical structures can lead to a continuum of exciting possibilities, from advanced training systems, to planning and per-operative guidance through the combined use of patient-specific models and robotics. The SHACRA team was created in 2010 with primary objectives to address some of the key scientific problems of the multidisciplinary field of computer-based medical simulation, in particular patient-specific anatomical and biomechanical modeling, advanced numerical solvers, physiological

modeling, and new interaction models. In parallel to these scientific objectives, we also proposed to focus on a number of applications, through close collaborations with clinicians. Our recent integration within the IHU1 in Strasbourg illustrates the relevance, and potential, of our research. To support these ambitious objectives, and allow us to develop prototypes that can be assessed by clinicians, we are leading a national initiative on medical simulation with several key partners, and we are also leading the development of a common software framework (SOFA) on which all of our research is built.

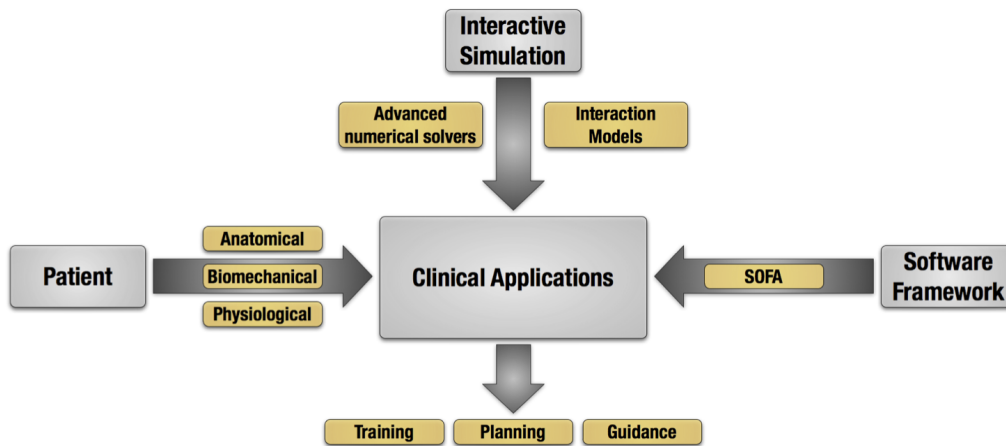


Figure 1. Overview of the team objectives (yellow boxes).

## 2.2. Challenges

Our main objectives for the evaluation period were to propose a number of solutions for more realistic, and faster simulations in the context of medical training. The main idea is that the simulations we develop should be computed in real (or near real) time, and that the presence of a user in the loop should be accounted for (through the use of dedicated hardware devices, haptic feedback and robust algorithms). This requires to develop accurate models, coupled with fast and robust computational strategies. The research directions we propose to follow essentially aim at improving the realism and fidelity of interactive simulations of medical procedures. This increase in realism will permit to address new clinical applications, in particular pre-operative planning and per-operative guidance, that currently rely on imaging techniques, but could greatly benefit from simulation techniques, thus enabling what we call *simulation-guided therapy*. We have identified several key areas where important improvements remain necessary to reach these objectives. Most of these research areas are at the intersection between several scientific domains. They include real-time biophysical models (to define new models describing soft tissue deformation or physiological phenomena, and to develop computational strategies to enable real-time computation even for complex models), interaction models (to compute tissue-tool interactions, and to model complex systems as a combination of different models), and models of therapy (to describe the action of medical devices on the anatomy whether this action is mechanical, electrical or chemical). The SOFA framework will be used to synthesize our various contributions and integrate them in a series of prototypes. These prototypes will span across several clinical areas and will serve as a basis for transitioning from training to planning to guidance. To pursue these directions we have assembled a team with a multidisciplinary background, and have established a series of key collaborations, with academic and clinical partners. We also leverage the work done through a national initiative on medical simulation and the SOFA framework in order to accelerate our research activities and deliver proofs of concepts. And in 2011, we took the opportunity to strengthen our clinical environment by participating to the creation of (and then joining) the IHU in Strasbourg.

## 2.3. Highlights of the Year

### 2.3.1. Scientific exhibition for the french government

The intergovernmental seminar on digital sciences was held in february at the University of Cergy-Pontoise. Within this context, the team has exhibited a demonstration of a cataract surgery simulator which is dedicated to train surgeons to a new cost-effective cataract surgery procedure MSICS (*manual small incision cataract surgery*). This simulator was developed at Inria and has been transferred to the start-up InSimo.



Figure 2. Demonstration of a cataract surgery simulator during the intergovernmental seminar on digital sciences.

### 2.3.2. Best Papers

We received the runner-up best paper award for the paper published in ISMAR 2013, the leading conference in Augmented and Mixed Reality.

BEST PAPER AWARD :

**[22] Image-guided Simulation of Heterogeneous Tissue Deformation For Augmented Reality during Hepatic Surgery in ISMAR - IEEE International Symposium on Mixed and Augmented Reality 2013.**

N. HAOUCHINE, J. DEQUIDT, I. PETERLIK, E. KERRIEN, M.-O. BERGER, S. COTIN.

## 3. Research Program

### 3.1. Real-time biophysical models

The principal objective of this scientific challenge is the modeling of the operative field, *i.e.* the anatomy and physiology of the patient that will be directly or indirectly targeted by a medical intervention. This requires to describe various phenomena such as soft-tissue deformation, fluid dynamics, electrical diffusion, or heat transfer. These models will help simulate the reaction of the patient's anatomy to the procedure, but also represent the behavior of complex organs such as the brain, the liver or the heart. A common requirement across these developments is the need for fast, possibly real-time, computation.

#### 3.1.1. Real-time biomechanical modeling of solid structures

Soft tissue modeling holds a very important place in medical simulation. A large part of the realism of a simulation, in particular for surgery or laparoscopy simulation, relies upon the ability to describe soft tissue response during the simulated intervention. Several approaches have been proposed over the past ten years to model soft-tissue deformation in real-time (mainly for solid organs), usually based on elasticity theory and a finite element approach to solve the equations. We were among the first to propose an approach [3] using different computational strategies. Although significant improvements were obtained later on (for instance

with the use of co-rotational methods to handle geometrical non-linearities) these works remain of limited clinical use as they essentially rely on linearized constitutive laws, and are rarely validated. An important part of our research remains dedicated to the development of new, more accurate models that are compatible with real-time computation. Such advanced models will not only permit to increase the realism of future training systems, but they will act as a bridge toward the development of patient-specific preoperative planning as well as augmented reality tools for the operating room.

### **3.1.2. Real-time biomechanical modeling of hollow structures**

A large number of anatomical structures in the human body are vascularized (brain, liver, heart, kidneys, etc.) and recent interventions (such as interventional radiology procedures) rely on the vascular network as a therapeutical pathway. It is therefore essential to model the shape and deformable behavior of blood vessels. This can be done at two levels, depending of the objective. The global deformation of a vascular network can be represented using the vascular skeleton as a deformable (tree) structure, while local deformations need to be described using models of deformable surfaces. Other structures such as aneurysms, the colon or stomach can also benefit from being modeled as deformable surface, and we can rely on shell or thin plate theory to reach this objective.

### **3.1.3. Real-time blood flow**

Beyond biomechanical modeling of soft tissues, an essential component of a simulation is the modeling of the functional interactions occurring between the different elements of the anatomy. This involves for instance modeling physiological flows. We are particularly interested in the problem of fluid flow in the context of vascular interventions, such as the simulation of three-dimensional turbulent flow around aneurysms to better model coil embolization procedures. A few studies have focused on aneurysm-related hemodynamics before and after endovascular coil embolization. As they rely on commercial software, the computation times (dozens of hours in general) are incompatible with interactive simulation or even clinical practice. Our objective is to propose new numerical approaches to reach (near) real-time computation of 3D flows without compromising the accuracy of the solution.

### **3.1.4. Real-time electrophysiology**

Electrophysiology plays an important role in the physiology of the human body, for instance by inducing muscles motion, and obviously through the nervous system. Also, many clinical procedures rely on electrical stimulation, such as defibrillation, neuromuscular or deep brain stimulation for instance. Yet, the modeling and the simulation of this phenomenon is still in its early stages. Our primary objective is to focus on cardiac electrophysiology, which plays a critical role in the understanding of heart mechanisms, and also in the planning of certain cardiac procedures. We propose to develop models and computational strategies aimed at real-time simulation, and to also provide means to define patient-specific parameterizations of the model(s).

## **3.2. Interaction models**

### **3.2.1. Constraint models and boundary conditions**

To simulate soft-tissue deformations accurately, the modeling technique must account for the intrinsic behavior of the modeled organ as well as for its biomechanical interactions with surrounding tissues or medical devices. While the biomechanical behavior of important organs (such as the brain or liver) has been studied extensively in the past, only few works exist dealing with the mechanical interactions between the anatomical structures. For tissue–tool interactions, most techniques rely on simple contact models, whereas advanced phenomena such as friction are rarely taken into account. While simplifications can produce plausible results in the case of interaction between the manipulator of a laparoscopic instrument and the surface of an organ, it is generally an insufficient approximation. As we move towards the simulations for planning or rehearsal, accurate modeling of contacts is playing an increasingly important role. For instance, we have shown in [30] and [31] that complex interactions between a coil and aneurysm, or alternatively between a flexible needle and soft-tissue can be computed in real-time. In laparoscopic surgery, the main challenge is represented by



modeling of interactions between anatomical structures rather than only between the instruments and the surface of the organ. Consequently, our objective was to model accurately the contacts with friction and other type on non-smooth interactions in a heterogeneous environment and to allow for stable haptic rendering. When different time integration strategies are used, another challenge is to compute the contact forces in such a way that integrity and stability of the overall simulation are maintained. Our objective was to propose a unified definition of such various boundary conditions and develop new numerical methods for simulations of heterogeneous objects.

### **3.2.2. Coupled biophysical systems**

Research dealing with interactive medical simulations is currently limited to (bio-)mechanical aspects. However, an important step needs to be done to capture more precisely the complex nature of human organs such as liver or heart: the liver can be regarded as a composite structure made of parenchyma, vessels and a capsule, while a complete simulation of heart requires a coupled electro-mechanical model. Moreover, computing the interactions (or coupling) between anatomical structures can be useful for a simulation of larger systems; for instance we are investigating the modeling of connective tissues. Since the solutions to the above-mentioned problems usually lead to very large systems of equations, our strategy is based on approach similar to that used in domain-decomposition: instead of solving the large system at once, we propose techniques where one system per model is solved in order to improve the efficiency of solution procedures.

## **3.3. Towards pre-operative planning and per-operative guidance**

Image-guided therapy is a recent area of research that has the potential to bridge the gap between medical imaging and clinical routine by adapting pre-operative data to the time of the procedure. Several challenges are typically related to image-guided therapy, such as multi-modality image registration, which serves to align pre-operative images onto the patient. As most procedures deal with soft-tissues, elastic registration techniques are necessary to perform this step. Novel registration techniques began to account for soft tissue deformation using physically-based methods. Yet, several limitations still hinder the use image-guided therapy in clinical routine. First, as registration methods become more complex, their computation time increases, thus lacking responsiveness. Second, as we have seen previously, many factors influence the deformation of soft-tissues, from patient-specific material properties to boundary conditions with surrounding anatomy. Another very similar, and related, problem is augmented reality, i.e. the real-time superposition of a virtual model onto the reality. In a clinical context, this can be very useful to help "see through" the anatomy. In this case, however, real-time registration of the virtual information onto the patient is mandatory. Our objective in this area is to combine our expertise in real-time soft-tissue modeling, complex interactions with image data to provide accurate and real-time registration, deformation, and tracking of virtual anatomical structures onto the patient.

The predictive capabilities of computer simulations may also be used to improve minimally invasive surgical procedures. While simulation results are sensitive to model parameters, initial and boundary conditions, we aim at combining computer-vision algorithms and simulation algorithms in order to produce dynamic data-driven simulation in clinical applications. The main idea is to use computer-vision algorithms from pre-operative diagnoses or per-operative video streams in order to extract meaningful data to feed the simulation engine and thus to increase the accuracy of the simulation. Clinical outcomes are expected in interventional radiology where the guidance is based on fluoroscopic imaging modality inducing high absorbed dose of X-rays for the patient and the clinical staff. In that context, using the prediction capabilities of the simulation may decrease the acquisition frequency of images, leading to a lower exposure of X-rays. Our objective in this area is to combine our expertise in patient-specific modeling and constraint models to achieve the dynamic coupling between images, pre-operative data and computer simulation.

# **4. Application Domains**

## **4.1. Medical Simulation**

Some of the scientific challenges described previously can be seen in a general context (such as solving constraints between different types of objects, parallel computing for interactive simulations, etc.) but often it is necessary to define a clinical context for the problem. This is required in particular for defining the appropriate assumptions in various stages of the biophysical modeling. It is also necessary to validate the results. This clinical context is a combination of two elements: the procedure we attempt to simulate and the objective of the simulation: training, planning or per-operative guidance. Several simulators applications are being developed in the team for instance Interventional Cerebro- and Cardio-vascular Radiology, Minimally-invasive ear surgery, Deep-Brain Stimulation planning...

It is important also to note that developing these applications raises many challenges and as such this step should be seen as an integral part of our research. It is also through the development of these applications that we can communicate with physicians, and validate our results. SOFA will be used as a backbone for the integration of our research into clinical applications.

## 4.2. Robotics

Contrary to rigid robots, the number of degrees of freedom (dof) of soft robots is infinite. On the one hand, a great advantage is to multiply the actuators and actuating shapes in the structure to expand the size of the workspace. In the other hand, these actuators are coupled together by the deformation of the robot which makes the control very tricky. Moreover, if colliding their direct environment, the robots may deform and also deform the environment, which complicates even more the control.

This project would build on our recent results, that use a real-time implementation of the finite element method to compute adequately the control of the structure. The present results allow to compute, in real-time, an inverse model of the robot (i.e. provide the displacements of the actuator that creates a desired motion of the end effector of the robot) for a few number of actuators and with simple interactions with its environment. However, the design of the robots, as well as the type of actuator used are far from optimal. The goal of this work is to improve the control methods especially when the robot is in interaction with its environment (by investigating feedback control strategies and by increasing the number of actuators that can be piloted) and to investigate new applications of these devices in medicine (especially for surgical robotics but not only...) and HCI (game, entertainment, art...).

## 5. Software and Platforms

### 5.1. SOFA

SOFA <http://www.sofa-framework.org> is an open-source software framework targeted at interactive computational (medical) simulation. The idea of SOFA was initiated by members of the SHACRA team, and strongly supported by Inria through a development program that we lead. SOFA facilitates collaborations between specialists from various domains, by decomposing complex simulators into components designed independently. Each component encapsulates one of the key aspects of a simulation, such as the degrees of freedom, the forces and constraints, the differential equations, the linear solvers, the collision detection algorithms or the interaction devices. The simulated objects can be represented using several models, each of them optimized for a different task such as the computation of internal forces, collision detection, haptics or visual display. These models are synchronized during the simulation using a mapping mechanism. CPU and GPU implementations can be transparently combined to exploit the computational power of modern hardware architectures. Thanks to this flexible yet efficient architecture, SOFA can be used as a test-bed to compare models and algorithms, or as a basis for the development of complex, high-performance simulators. As proof of its success, SOFA has been downloaded nearly 150,000 times, and is used today by many research groups around the world, as well as a number of companies. The mailing list used to exchange with the community includes several hundreds of researchers, from about 50 different institutions. SOFA is at the heart of a number of research projects, including cardiac electro-physiology modeling, interventional radiology planning and guidance, planning for cryosurgery and deep brain stimulation, robotics, percutaneous procedures, laparoscopic

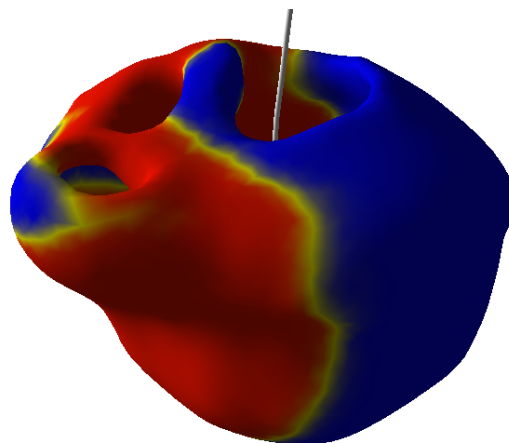
surgery, non-rigid registration, etc. SOFA is the only software developed by our team, but practically speaking it is a collection of plugins (each one aimed at a specific application) organized around a common core that provides a large number of functionalities. As mentioned previously, SOFA is currently used by a number of companies (Siemens Corporate Research, Digital Trainers, Epona Medical, Moog, SenseGraphics, etc.) and also provides the key technology on which our newly created start-up (InSimo) is relying. We strongly believe that today SOFA has become a reference for academic research, and is increasingly gaining recognition for product prototyping and development. The best illustration of this worldwide positioning is the role of SOFA in the challenge set by the HelpMeSee foundation to win the contract for the development of a very ambitious and high-risk project on cataract surgery simulation.

We also gave a 4 hours workshop on SOFA at MMVR/NextMed conference in february 2013 in San Diego. This workshop was done in collaboration with the swedish company SenseGraphics. The topic was to demonstrate the setup of a dental surgery simulation in Sofa, and use SenseGraphics visual tools for the rendering. The attendees feedback was beyond our expectations, with an unexpected interest in new SOFA features like the SofaPython plugin. Still about SOFA, like last year we gave in october a 3 days training session in Montpellier for about twenty SOFA beginners (mostly engineers). These are new engineers of the three teams involved in SOFA development, and employees of companies using SOFA in their business. Last, a "SOFA Day" in november in prelude of the Vriphys conference gave us a unique opportunity to meet SOFA users from various research institutes or companies, and exchange about the future improvements and development of the engine. We use these occasions to share and discuss with SOFA users, to refine the roadmap and stay tuned with our audience.

## 6. New Results

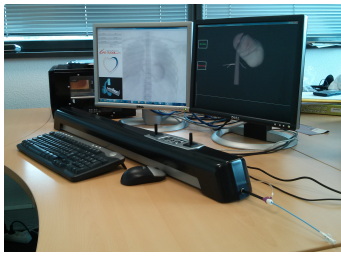
### 6.1. Electrophysiology

Cardiac arrhythmia is a very frequent pathology that comes from an abnormal electrical activity in the myocardium. This work aims at developing a training simulator for interventional radiology and thermo-ablation of these arrhythmias. After tackling the issue of fast electrophysiology, a first version of our training simulator was proposed.

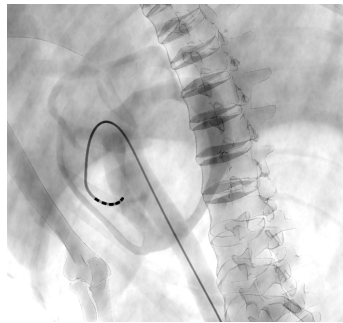


*Figure 3. Cardiac electrophysiology computed on a patient-specific geometry*

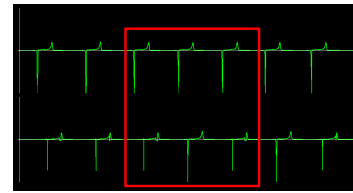
The first main contribution of this work is the interactive catheter navigation inside a moving venous system and a beating heart. The virtual catheterization reproduces navigation issues that can be solved using a bending catheter. Second, our real-time GPU electrophysiology model allows interactions during the simulation such as extra-cellular potential measurement, RF ablation, and electrical stimulation. An innovative management of the computational units based on multithreading offers performances close to real-time. This framework is therefore a substantial step towards realistic and highly efficient virtual training systems in cardiology. As future work, we intend to use patient-specific data in our framework so that cardiologists could quantitatively assess the realism of our virtual training.



(a) Setup of the System



(b) Simulation of Catheter Navigation



(c) Electrophysiological Signals

Figure 4. The first simulation dedicated to electrocardiology training

## 6.2. Cryoablation

A new project started this year around cryotherapy. This technique consists in inserting needles that freezing the surrounding tissues, thus immediately leading to cellular death of the tissues. Cryoablation procedure is used in many medical fields for tumor ablation, and even starts being used in cardiology. In this scope, we build a simulator able to place the cryoprobes and run a simulation representing the evolution of iceballs in living tissues.



Figure 5. Simulation framework for cryoablation planning

### 6.3. Stapedotomy

Stapedotomy is a challenging procedure of the middle ear microsurgery, since the surgeons is in direct contact with sensitive structures such as the ossicular chain. This procedures is taught and performed in the last phase of the surgical apprenticeship. To improve surgical teaching, we propose to use a virtual surgical simulator based on a finite element model of the middle ear. The static and dynamic behavior of the developed finite element model was successfully compared to published data on human temporal bones specimens. A semi-automatic algorithm was developed to perform a quick and accurate registration of our validated mechanical atlas to match the patient dataset. This method avoids a time-consuming work of manual segmentation, parameterization, and evaluation. A registration is obtained in less than 260 seconds with an accuracy close to a manual process and within the imagery resolution. The computation algorithms, allowing carving, deformation of soft and hard tissues, and collision response, are compatible with a real-time interactive simulation of a middle ear procedure. As a future work, we propose to investigate new robotized procedures of the middle ear surgery in order to develop new applications for the RobOtol device and to provide a training tool for the surgeons.

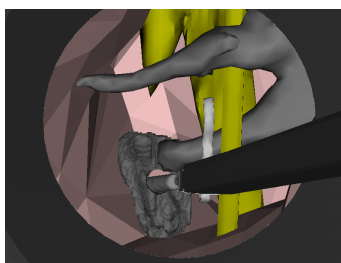


Figure 6. Simulation of the stapedotomy procedure.

### 6.4. Radiotherapy planning

The main challenge of radiotherapy treatment is to irradiate the tumor while sparing the surrounding healthy tissues. In the case of throat cancer, the complexity of the therapy treatment is due to the proximity of organs at risk such as the two parotid glands. The parotid glands are the main salivary glands. An overdose of radiation in these glands may cause xerostomia, which is a medical term for the symptom of dryness in the mouth, or in other words, a lack of saliva. This disease affect significantly the life of the patient: difficulty talking, tasting, chewing, swallowing, excessive thirst, constant pain in the throat etcetera. A radiation therapy treatment of throat cancer takes from 5 to 7 weeks. The treatment is planned several days before the therapy. The planning consist in contouring each organ of the area on CT-scan images and defining the dose of radiation to deliver to each of these organs. This stage is lengthy and takes around two hours per patient. Yet, some anatomical variations occur in the course of the treatment, mainly due to the weight loss of the patients. These variations compromise the safety of the healthy tissues, because the planned treatments is no more up to date. For now, the physicians have no solution good enough to handle these changes. Xerostomia affects around 20 per-cent of the patients suffering from throat cancer.

The main idea of this work is to create an interface that the physicians could use to redo the planning when it is needed, when the anatomical changes are significant. The purpose is to give to them the possibility to use what they see on images, to recreate the right shape of the contours without recontouring each images, and in a reasonable time. This interface will use their knowledge to determine the new shape of the organs. The work does not aim at providing a fully automatic method because it would reduce its acceptance by the physicians. As the method is based on the input of the physician, they can control the deformation based on images but also on their knowledge.

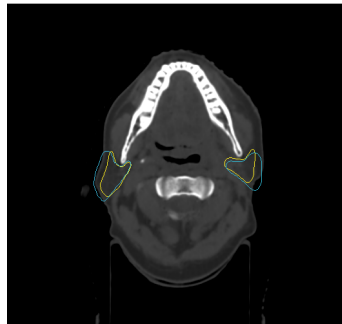


Figure 7. Screenshot of our radiotherapy planning tool.

## 6.5. Image-based diagnoses

In the context of the female pelvic medicine, image-based diagnoses of pelvic floor disorders like prolapse or endometriosis rely on mechanical indicators, such as mobilities of organs and shear displacements between organs. This information would be useful for both precise diagnoses and planning of surgical procedure. Involving numerical tools for diagnoses and surgery planing becomes increasingly interesting for physicians in clinical uses. The advantages of numerical models are not only in visualization, but also in quantitative measurements on a group of organs, such as their shapes and their relative movements. The processing pipeline includes patient data retrieval, image analysis, patient-specific modeling and biomechanical simulation. Our work consists in proposing new methods and algorithms for modeling the 3D anatomy of specific patients based on image data. This model should be compatible with the requirements of a biomechanical simulation. Moreover, we aim at developing new image processing tools for analyzing 2D dynamic MRI (to assess the mobilities of the pelvic system by extracting certain mechanical indicators from images) and for comparison with simulations.

Registration between geometric models and images remains a major challenge in these applications. We proposed a new model-to-image registration approach which was developed and tested for segmentation of organs in 2D images and for tracking the motion of pelvic organs from 2D dynamic MRI. Thanks to this technique, evaluation of the level of shear strain that is encountered by the fascias (connective tissues between organs) during the motion became possible. This tool could help in early diagnostic of prolapse. In the next step, our objective is to extend this method for adapting it to 3D reconstruction (with 3D geometric models and 3D MR images) and for the comparison of 3D simulations with deformable images.

## 6.6. Dynamic Deformations Simulated at Different Frequencies

The dynamic response of deformable bodies varies significantly in dependence on mechanical properties of the objects: while the dynamics of a stiff and light object (e. g. wire or needle) involves high-frequency phenomena such as vibrations, much lower frequencies are sufficient for capturing dynamic response of an object composed of a soft tissue. Yet, when simulating mechanical interactions between soft and stiff deformable models, a single time-step is usually employed to compute the time integration of dynamics of both objects. However, this can be a serious issue when haptic rendering of complex scenes composed of various bodies is considered. In this work, we present a novel method allowing for dynamic simulation of a scene composed of colliding objects modelled at different frequencies: typically, the dynamics of soft objects are calculated at frequency about 50 Hz, while the dynamics of stiff object is modeled at 1 kHz, being directly connected to the computation of haptic force feedback. The collision response is performed at both low and high frequencies employing data structures which describe the actual constraints and are shared between the high and low frequency loops. During the simulation, the realistic behaviour of the objects according to the

mechanical principles (such as non-interpenetration and action-reaction principle) is guaranteed. We have shown several scenarios involving different bodies in interaction, demonstrating the benefits of the proposed method. This research has been published at IROS 2013.

## **6.7. Simulation of Lipofilling Reconstructive Surgery**

We have developed a method to simulate the outcome of reconstructive facial surgery based on fat-filling. Facial anatomy is complex: the fat is constrained between layers of tissues which behave as walls along the face; in addition, connective tissues that are present between these different layers also influence the fat-filling procedure. To simulate the end result, we have proposed a method which couples a 2.5D Eulerian fluid model for the fat and a finite element model for the soft tissues. The two models are coupled using the computation of the mechanical compliance matrix. We had two contributions: a solver for fluids which couples properties of solid tissues and fluid pressure, and an application of this solver to fat-filling surgery procedure simulation. This research has been published at MICCAI 2013.

## **6.8. Real-time simulation of contact and cutting of heterogeneous soft-tissues**

We have developed a new numerical method for interactive (real-time) simulations, which considerably improves the accuracy of the response of heterogeneous soft-tissue models undergoing contact, cutting and other topological changes. It provides an integrated methodology able to deal both with the ill-conditioning issues associated with material heterogeneities, contact boundary conditions which are one of the main sources of inaccuracies, and cutting which is one of the most challenging issues in interactive simulations. Our approach is based on an implicit time integration of a non-linear finite element model. To enable real-time computations, we propose a new preconditioning technique, based on an asynchronous update at low frequency. The preconditioner is not only used to improve the computation of the deformation of the tissues, but also to simulate the contact response of homogeneous and heterogeneous bodies with the same accuracy. We also address the problem of cutting the heterogeneous structures and propose a method to update the preconditioner according to the topological modifications. Finally, we have applied our approach to three challenging demonstrators: i) a simulation of cataract surgery ii) a simulation of laparoscopic hepatectomy iii) a brain tumor surgery. This research was done in collaboration with the University of Cardiff and has been published in the journal *Media* this year.

## **6.9. Control of Elastic Soft Robots**

In this work, we present a new method for the control of soft robots with elastic behavior, piloted by several actuators. The central contribution of this work is the use of the Finite Element Method (FEM), computed in real-time, in the control algorithm. The FEM based simulation computes the nonlinear deformations of the robots at interactive rates. The model is completed by Lagrange multipliers at the actuation zones and at the end-effector position. A reduced compliance matrix is built in order to deal with the necessary inversion of the model. Then, an iterative algorithm uses this compliance matrix to find the contribution of the actuators (force and/or position) that will deform the structure so that the terminal end of the robot follows a given position. Additional constraints, like rigid or deformable obstacles, or the internal characteristics of the actuators are integrated in the control algorithm. We illustrate our method using simulated examples of both serial and parallel structures and we validate it on a real 3D soft robot made of silicone.

# **7. Bilateral Contracts and Grants with Industry**

## **7.1. Bilateral Contracts with Industry**

InSimo is a startup we created in January 2013, after two years of thinking, maturation and incubation. Its founding members are all former or actual team members of SHACRA: Jeremie Allard, Juan Pablo de la Plata Alcalde and Pierre Jean Bensoussan have joined the operation team, while Stephane Cotin and Christian

Duriez serve as scientific advisors. The business model of the company is based on the SOFA platform and its community to transfer state-of-the-art simulation technologies into commercially-supported software components that medical simulator vendors can integrate into their products. The goal is to foster the creation of a new generation of medical simulators, highly realistic, faster to develop, allowing a broader commercial offer and novel uses. InSimo participated to the 2012 OSEO / MESR national innovative technology company creation competition (Emergence category) and was selected as the best project in the Alsace region as well as one of the three projects highlighted at the national level. InSimo also won the HelpMeSee contract (in partnership with Moog and SenseGraphics) and entered in February 2013 into a 3-year development phase to build a first batch of 100 MSICS simulators.

## 7.2. Bilateral Grants with Industry

We have started a collaboration with INSERM - UMR-S 867 (minimal invasive and robotized otological surgery) Faculté de Médecine Paris Diderot Paris 7 and with the company Collin SA (Bagneux, France) which is developing some activities in the domain of the head and neck (surgical robot such as RobOtol, middle ear implants, surgical instruments, surgical navigation, ...). The objective of this project is to obtain a simulation tool applied to the ear surgery for both training and planning of conventional and robotized middle ear surgery. In addition, the aim of this work is to provide a tool able to explore, develop and assess new robotized procedures using a tele-operated device called RobOtol. Guillaume Kazmitcheff is doing his PhD in the context of this collaboration: he is paid by a CIFRE contract with Collin, he is mainly working with the INSERM team but the design of the simulation is done in collaboration with our group and he is enrolled in the university of Lille 1.

# 8. Partnerships and Cooperations

## 8.1. National Initiatives

### 8.1.1. *Sofa, ADT*

SOFA Large Scale Development Initiative (ADT) : the SOFA project (Simulation Open Framework Architecture) is an international, multi-institution, collaborative initiative, aimed at developing a flexible and open source framework for interactive simulations. This will eventually establish new grounds for a widely usable standard system for long-term research and product prototyping, ultimately shared by academic and industrial sites. The SOFA project involves 3 Inria teams, SHACRA, IMAGINE and ASCLEPIOS. The development program of the ADT started in 2007.

### 8.1.2. *ANR Acoustic*

The main objective of this project is to develop an innovative strategy based on models for helping decision-making process during surgical planning in Deep Brain Stimulation. Models will rely on different levels involved in the decision-making process; namely multimodal images, information, and knowledge. Two types of models will be made available to the surgeon: patient specific models and generic models. The project will develop methods for 1) building these models and 2) automatically computing optimal electrodes trajectories from these models taking into account possible simulated deformations occurring during surgery. The project belongs to the multidisciplinary domain of computer-assisted surgery (CAS). Computer assisted surgery aims at helping the surgeon with methods, tools, data, and information all along the surgical workflow. More specifically, the project addresses surgical planning and surgical simulation in Image Guided Surgery. It is related to the exponentially growing surgical treatment of Deep Brain Stimulation (DBS), originally developed in France by Pr. Benabid (Grenoble Hospital). The key challenges for this research project are 1) to identify, extract, gather, and make available the information and knowledge required by the surgeon for targeting deep brain structures for stimulation and 2) to realistically simulate the possible trajectories.



### 8.1.3. IHU, Strasbourg

Our team has been selected to be part of the IHU of Strasbourg. This new institute, for which funding (67M€) has just been announced, is a very strong innovative project of research dedicated to future surgery of the abdomen. It will be dedicated to minimally invasive therapies, guided by image and simulation. Based on interdisciplinary expertise of academic partners and strong industry partnerships, the IHU aims at involving several specialized groups for doing research and developments towards hybrid surgery (gesture of the surgeon and simulation-based guidance). Our group and SOFA have an important place in the project. Since September 2011 a part of our team is located within the IHU, to develop a number of activities in close collaboration with clinicians.

### 8.1.4. ANR IDEaS

IDEaS is a project targeted at per-operative guidance for interventional radiology procedures. Our main goal is to provide effective solutions for the two main drawbacks of interventional radiology procedures, namely: reduce radiation exposure and provide a fully 3D and interactive visual feedback during the procedure. To do so, our project relies on an original combination of computer vision algorithms and interactive physics-based medical simulation. Computer vision algorithms extract relevant information (like the actual projected shape of the guide-wire at any given time) from X-ray images, allowing adjusting the simulation to real data. Conversely, computer-based simulation is used as a sophisticated and trustful predictor for an improved initialization of computer vision tracking algorithms. Many outcomes may be expected both in scientific and clinical aspects. On the scientific side, we believe a better understanding of how real data and simulation should be merged and confronted must lead, as a natural by-product, to image-based figures of merit to actually validate computer-based simulation outputs against real and dynamic data. A more accurate identification of the factors limiting the realism of simulation should follow with a rebound impact on the quality of the simulation itself. An actual integration of a mechanical model into the loop will improve the tracking. We firmly believe mechanical constraints can supplement the image data such that dynamic single view reconstruction of the interventional devices will be possible. On the clinical side, using the prediction capabilities of the simulation may decrease the need for X-ray images at high rates, thus leading to lower exposure to radiations for the patients and surgical staff. Finally, the output of the simulation is the 3D shape of the tool (e.g. guide-wire or catheter), but not only. Additional information may be visualized, for instance pressure of the catheter on the arterial wall, to prevent vessel wall perforations, or reduce stress on the arterial wall to prevent spasm. More generally, richer information on the live procedure may help surgeons to reduce malpractice or medical errors.

## 8.2. European Initiatives

### 8.2.1. FP7 Projects

#### 8.2.1.1. RASimAs

Type: COOPERATION

Defi: NA

Instrument: Specific Targeted Research Project

Objectif: NC

Duration: nov 2012 - oct 2015

Coordinator: RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE (RWTH), Aachen, Germany

Partner: UNIVERSITAETS KLINIKUM AACHEN, Germany // RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE, Germany // BANGOR UNIVERSITY, United Kingdom // UNIVERSITY COLLEGE CORK, NATIONAL UNIVERSITY OF IRELAND, CORK, Ireland // UNIVERSIDAD REY JUAN CARLOS, Spain // FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS, Greece // ZILINSKA UNIVERZITA V ZILINE, Slovakia // KATHOLIEKE UNIVERSITEIT LEUVEN, Belgium // SINTEF Norway, SENSEGRAPHICS, Sweden

Inria contact: Stéphane Cotin

Abstract: Regional anaesthesia has been used increasingly during the past four decades. This is addressed to the perceived advantages of reduced postoperative pain, earlier mobility, shorter hospital stay, and significantly lower costs. Current training methods for teaching regional anaesthesia include cadavers, video teaching, ultrasound guidance, and simple virtual patient modeling. These techniques have limited capabilities and do not consider individual anatomy. The goal of this project is to increase the application, the effectiveness and the success rates of RA and furthermore the diffusion of the method through the development VPH models for anaesthesia. The goal of the SHACRA team is to provide the computational infrastructure for the physics-based simulation and to propose new methods for patient-specific modeling and simulation of soft tissues and their interaction with the needle, including its effect on nerve physiology.

## 8.3. International Initiatives

### 8.3.1. Participation In other International Programs

Jeremie Dequidt has been a member of the Inria delegation at the India-France Technology Summit <http://indiafrancesummit.org/>. During a technology showcase, he presented SOFA and various medical simulators. He also was part of a roundtable about biotechnologies.

## 8.4. International Research Visitors

### 8.4.1. Visits to International Teams

Christian Duriez has been invited during one week (last week of October) by the JRL team in AIST Tsukuba Japan, to work with Pr. Eiichi Yoshida on using real-time simulation for the control of robotic tasks with deformable objects.

# 9. Dissemination

## 9.1. Scientific Animation

### 9.1.1. VRIPHYS 2013

VRIPHYS 2013 took place in Lille at the end of November: Christian Duriez and Jeremie Dequidt organized the conference with help from Nazim Haouchine and Hugo Talbot. The conference was preceded by a workshop for the users of the SOFA framework. This event was a real success: 60 persons attended the conference (which is about 15 persons more than the previous years).

### 9.1.2. IPCAI 2013

Stéphane Cotin, Co-Organizer and PC Co-Chair, 2013, International Conference on Information Processing in Computer-Assisted Interventions (IPCAI, <http://www.ipcai.org>). on June 26, 2013 in Heidelberg, Germany.

### 9.1.3. Reviewing Activities

- Guillaume Kazmitcheff has been reviewer for the European Archives of Oto-Rhino-Laryngology journal.
- Jeremie Dequidt has been reviewer for the following conferences and journals:
  - Conference IEEE/RSJ IROS 2013
  - Conference IEEE WHC 2013
  - Conference MICCAI 2013
  - the journal Computer Methods and Programs in Biomedicine

and member of the following program committees:

- Conference VRIPHYS 2013
- Conference AFIG 2013
- Christian Duriez has been reviewer for the following conferences and journals:
  - Conference IEEE/RSJ IROS 2013
  - Conference iNaCoMM 2013
  - Conference IEEE VR 2013
  - Conference MICCAI 2013
  - the journal IEEE Transaction on Haptics
  - the journal IEEE Transactions on Visualization and Computer Graphics
  - the journal SCS Simulation
  - the journal the Visual Computer
  - the journal Computer Vision and Visual Understanding
  - ANR projects (Programme CONTINT)

and member of the following program committees:

- Conference VRIPHYS 2013
- Conference IEEE WHC 2013
- Stephane Cotin has been reviewer for the following conferences and journals:
  - Surgical Innovation (SRI)
  - Advanced Modeling and Simulation in Engineering Sciences

and member of the following program committees:

- MICCAI 2013
- IPCAI 2013

## 9.2. Teaching - Supervision - Juries

### 9.2.1. Teaching

Licence : Jeremie Dequidt, Computer Architecture, 25h, GIS3, Polytech Lille, France

Licence : Jeremie Dequidt, Advanced Programming, 25h, IMA3, Polytech Lille, France

Licence : Christian Duriez, Introduction to Finite Element Method, 16h, L3, ICAM, France

Licence : Julien Bosman, Programming, 60h, L1, Univ. Lille 1, France

Licence : Julien Bosman, Oriented Object Programming, 32h, L3, Univ. Lille 1, France

Master : Christian Duriez, Introduction to Finite Element Method, 16h, M1 Génie Ferroviaire, ICAM, France

Master : Christian Duriez, Advanced 3D models, 14h, M2 IVI, Univ. Lille 1, France

Master : Christian Duriez, Medical simulation and Haptic Rendering, 3h, M2, École Centrale de Lille, France

Master : Julien Bosman, GPU Computing introduction, 3h, M2 IVI, Univ. Lille 1, France

Master : Jeremie Dequidt, Advanced 3D models, 2h, M2 IVI, Univ. Lille 1, France

Master : Stephane Cotin, Course on advanced biomechanics, 10h, M2, Telecom Physique Strasbourg, France

Master : Stephane Cotin, Course on real-time soft tissue simulation, 20h, M2, Telecom Physique Strasbourg, France

### 9.2.2. Supervision

PhD in progress : Hugo Talbot, Interactive Patient-Specific Simulation of Cardiac Electrophysiology, 1st October 2010, Stéphane Cotin and Hervé Delingette

PhD in progress : Julien Bosman, Simulations à base de particules et interactions multi-physiques en temps-réel, 1st October 2011, Stéphane Cotin and Christian Duriez

PhD in progress : Guillaume Kazmitcheff, Dynamical modeling of the middle ear and interactions between organs and medical tools to develop a simulator applied to the otological surgery, 1st March 2011, Christian Duriez

PhD in progress : Ahmed Yureidini, Modélisation d'organes par fonctions implicites, 2009, Stéphane Cotin and Erwan Kerrien

PhD in progress : Vincent Majorczyk, Simulation de Fluide GPU, 2010, Stéphane Cotin

PhD in progress : Alexandre Bilger, Biomechanical simulation for Deep Brain Stimulation, 2011, Stéphane Cotin and Christian Duriez

PhD in progress : Zhifan Jiang, Recalage d'images déformables pour la biomécanique, 2011, Stéphane Cotin, Jérémie Dequidt, Mathias Brieu

PhD in progress : Mouhamadou Diallo, Modélisation biomécanique du prolapsus génital, 2011, Mathias Brieu, Pauline Lecomte, Christian Duriez

PhD in progress : Nazim Haouchine, Augmented Reality Tools for Minimally Invasive Hepatic Surgery, 2012, Stéphane Cotin, Marie-Odile Berger, Jérémie Dequidt

PhD in progress : Francois Dervaux, Image driven simulation for interventional radiology procedures, 2012, Stéphane Cotin, Jérémie Dequidt, Erwan Kerrien

PhD in progress : Rosalie Plantefève, 2013, Stéphane Cotin

### 9.2.3. Juries

Christian Duriez was in the examination committee of Coralie Escande, PhD, 12/2013.

Stéphane Cotin was in the examination committee of Sagar Umale (Strasbourg University, December 19th, 2012) and in the examination committee of Noura Faraj (Telecom ParisTech, June 3rd, 2013)

## 9.3. Popularization

### 9.3.1. Fête de la Science

Christian Duriez has been involved as a *Wandering Researcher* in the Fête de la science (french event that promotes science).

### 9.3.2. Exhibitions

Christian Duriez and Mario Sanz Lopez have been involved in the design and development of scientific and technological demonstrators for the *Plateau* (e.g. Showroom) Inria at Euratechnologies and for *The Labo* at Inria test laboratory.

### 9.3.3. Rencontre Inria-Industrie 2013

This was a public event taking place in Paris the 11th of June 2013. The new training system dedicated to electrocardiology and the recent deformable robot was presented.

### 9.3.4. IHU Scientific Days

At the occasion of the IHU Scientific days, we visited the IHU Strasbourg and several talks were done by members of the team: Alexandre Bilger, Stéphane Cotin, Jérémie Dequidt, Nazim Haouchine, Igor Peterlik, and Hugo Talbot.

### 9.3.5. Intergovernmental seminar

The intergovernmental seminar on digital sciences was held in february at the University of Cergy-Pontoise. Within this context, the team has exhibited a demonstration of a cataract surgery simulator which is dedicated to train surgeons to a new cost-effective cataract surgery procedure MSICS (*manual small incision cataract surgery*). This simulator was developed at Inria and has been transferred to the start-up InSimo.

## 10. Bibliography

### Major publications by the team in recent years

- [1] J. ALLARD, H. COURTECUISSÉ, F. FAURE. *Implicit FEM Solver on GPU for Interactive Deformation Simulation*, in "GPU Computing Gems Jade Edition", NVIDIA/Elsevier, October 2011, chap. 21
- [2] J. ALLARD, F. FAURE, H. COURTECUISSÉ, F. FALIPOU, C. DURIEZ, P. G. KRY. *Volume Contact Constraints at Arbitrary Resolution*, in "ACM Transactions on Graphics (Proceedings of SIGGRAPH 2010)", August 2010, vol. 29(3), <http://www.sofa-framework.org/projects/ldi>
- [3] S. COTIN, H. DELINGETTE, N. AYACHE. *Real-Time Elastic Deformations of Soft Tissues for Surgery Simulation*, in "IEEE Transactions on Visualization and Computer Graphics", 1999, vol. 5, n<sup>o</sup> 1, pp. 62–73
- [4] J. DEQUIDT, J. LENOIR, S. COTIN. *Interactive Contacts Resolution Using Smooth Surface Representation*, in "Proc. Medical Image Computing and Computer-Assisted Interventions (MICCAI)", 2007, pp. 850-857
- [5] J. DEQUIDT, M. MARCHAL, C. DURIEZ, S. COTIN. *Interactive Simulation of Embolization Coils: Modeling and Experimental Validation*, in "Medical Image Computing and Computer Assisted Intervention (MICCAI)", 2008, pp. 695-702
- [6] C. DURIEZ, S. COTIN, J. LENOIR, P. F. NEUMANN. *New Approaches to Catheter Navigation for Interventional Radiology Simulation*, in "Computer Aided Surgery", 2006, vol. 11, pp. 300-308
- [7] C. DURIEZ, F. DUBOIS, A. KHEDDAR, C. ANDRIOT. *Realistic Haptic Rendering of Interacting Deformable Objects in Virtual Environments*, in "IEEE Transactions on Visualization and Computer Graphics", 2006, vol. 12, n<sup>o</sup> 1, pp. 36–47, <http://dx.doi.org/10.1109/TVCG.2006.13>
- [8] A. KERDOK, S. COTIN, M. OTTENSMEYER, A. GALEA, R. HOWE, S. DAWSON. *Truth Cube: Establishing Physical Standards for Real-Time Soft Tissue Simulation*, in "Medical Image Analysis", September 2003, vol. 7, n<sup>o</sup> 3
- [9] V. LUBOZ, X. WU, K. KRISIAN, C. WESTIN, R. KIKINIS, S. COTIN, S. DAWSON. *A segmentation and reconstruction technique for 3D vascular structures*, in "Medical Image Computing and Computer Assisted Intervention (MICCAI)", 2005, pp. 43-50
- [10] Y. WEI, S. COTIN, F. LE, J. ALLARD, P. CHUNHUONG. *Toward Real-time Simulation of Blood-Coil Interaction during Aneurysm Embolization*, in "Medical Image Computing and Computer Assisted Intervention (MICCAI)", 2009

## Publications of the year

### Doctoral Dissertations and Habilitation Theses

- [11] C. DURIEZ. , *Simulation temps-réel d'interventions médicales impliquant des déformations et des interactions mécaniques entre les tissus et les outils (Manuscrit en anglais)*, Université des Sciences et Technologie de Lille - Lille I, February 2013, Habilitation à Diriger des Recherches, <http://hal.inria.fr/tel-00785118>

### Articles in International Peer-Reviewed Journals

- [12] A. BILGER, C. DURIEZ, S. COTIN. *Computation and Visualization of Risk Assessment in Deep Brain Stimulation*, in "Studies in Health Technology and Informatics", February 2014, <http://hal.inria.fr/hal-00881694>
- [13] J. DEQUIDT, H. COURTECUISSÉ, O. COMAS, J. ALLARD, C. DURIEZ, S. COTIN, E. DUMORTIER, O. WAVREILLE, J.-F. ROULAND. *Computer-based training system for cataract surgery*, in "Transactions of the Society for Modeling and Simulation International", 2013 [DOI : 10.1177/0037549713495753], <http://hal.inria.fr/hal-00855821>
- [14] M. GUIATNI, V. RIBOULET, C. DURIEZ, A. KHEDDAR, S. COTIN. *A Combined Force and Thermal Feedback Interface for Minimally Invasive Procedures Simulation*, in "IEEE/ASME Transactions on Mechatronics", June 2013, vol. 18, n<sup>o</sup> 3, pp. 1170-1181 [DOI : 10.1109/TMECH.2012.2197862], <http://hal.inria.fr/lirmm-00783583>
- [15] G. KAZMITCHEFF, M. MIROIR, Y. NGUYEN, E. FERRARY, O. STERKERS, S. COTIN, C. DURIEZ, A. BOZORG-GRAYELI. *Validation Method of a Middle Ear Mechanical Model to Develop a Surgical Simulator*, in "Audiology and Neurotology", 2013, in press [DOI : 10.1159/000356301], <http://hal.inria.fr/hal-00919918>
- [16] P. MOREIRA, I. PETERLIK, H. MARK, C. DURIEZ, S. COTIN, S. MISRA. *Modelling Prostate Deformation: SOFA versus Experiments*, in "Mechanical Engineering Research", 2013, vol. 3, n<sup>o</sup> 2, p64 p. [DOI : 10.5539/MER.v3n2p64], <http://hal.inria.fr/hal-00915244>
- [17] H. TALBOT, S. MARCHESSEAU, C. DURIEZ, M. SERMESANT, S. COTIN, H. DELINGETTE. *Towards an Interactive Electromechanical Model of the Heart*, in "Journal of the Royal Society Interface Focus", April 2013, vol. 3, n<sup>o</sup> 2 [DOI : 10.1098/RSFS.2012.0091], <http://hal.inria.fr/hal-00797354>

### International Conferences with Proceedings

- [18] J. BOSMAN, C. DURIEZ, S. COTIN. *Connective Tissues Simulation on GPU*, in "10th Workshop on Virtual Reality Interaction and Physical Simulation", Lille, France, 2013, <http://hal.inria.fr/hal-00916698>
- [19] F. DERVAUX, I. PETERLIK, J. DEQUIDT, S. COTIN, C. DURIEZ. *Haptic Rendering of Interacting Dynamic Deformable Objects Simulated in Real-Time at Different Frequencies*, in "IROS - IEEE/RSJ International Conference on Intelligent Robots and Systems", Tokyo, Japan, IEEE, November 2013, <http://hal.inria.fr/hal-00842866>
- [20] C. DURIEZ. *Control of Elastic Soft Robots based on Real-Time Finite Element Method*, in "ICRA 2013 IEEE International Conference on Robotics and Automation", Karlsruhe, France, 2013, <http://hal.inria.fr/hal-00823766>

- [21] N. HAOUCHINE, J. DEQUIDT, M.-O. BERGER, S. COTIN. *Deformation-based Augmented Reality for Hepatic Surgery*, in "Medicine Meets Virtual Reality, MMVR 20", San Diego, United States, February 2013, <http://hal.inria.fr/hal-00768372>
- [22] *Best Paper*  
N. HAOUCHINE, J. DEQUIDT, I. PETERLIK, E. KERRIEN, M.-O. BERGER, S. COTIN. *Image-guided Simulation of Heterogeneous Tissue Deformation For Augmented Reality during Hepatic Surgery*, in "ISMAR - IEEE International Symposium on Mixed and Augmented Reality 2013", Adelaide, Australia, October 2013, <http://hal.inria.fr/hal-00842855>.
- [23] G. KAZMITCHEFF, C. DURIEZ, M. MIROIR, Y. NGUYEN, O. STERKERS, A. BOZORG-GRAYELI, S. COTIN. *Registration of a Validated Mechanical Atlas of Middle Ear for Surgical Simulation*, in "MICCAI 2013", Nagoya, Japan, 2013, <http://hal.inria.fr/hal-00838431>
- [24] P. LECOMTE-GROSBRAS, M. NASSIROU - DIALLO, J.-F. WITZ, D. MARCHAL, J. DEQUIDT, S. COTIN, M. COSSON, C. DURIEZ, M. BRIEU. *Towards a better understanding of pelvic system disorders using numerical simulation*, in "Medical Image Computing and Computer Assisted Intervention", Nagoya, Japan, September 2013, <http://hal.inria.fr/hal-00831245>
- [25] V. MAJORCZYK, C. DURIEZ, S. COTIN, J. ALLARD. *Simulation of Lipofilling Reconstructive Surgery using coupled Eulerian Fluid and Deformable Solid Models*, in "Medical Image Computing and Computer Assisted Intervention Society", Nagoya, Japan, Springer, September 2013, <http://hal.inria.fr/hal-00838650>
- [26] H. TALBOT, M. LEKKAL, R. BÉSSARD-DUPARC, S. COTIN. *Interactive Planning of Cryotherapy Using Physically-Based Simulation*, in "MMVR 21 - Medicine Meets Virtual Reality - 2014", Manhattan Beach, California, United States, February 2014, <http://hal.inria.fr/hal-00918200>

### Conferences without Proceedings

- [27] G. KAZMITCHEFF, Y. NGUYEN, M. MIROIR, E. FERRARY, S. COTIN, C. DURIEZ, O. STERKERS. *Virtual Simulation of Stapedotomy Surgery*, in "ARO 2014", San Diego, CA, United States, 2014, <http://hal.inria.fr/hal-00919984>

### Books or Proceedings Editing

- [28] S. COTIN, P. JANNIN, D. BARRATT, N. NAVAB, G. FICHTINGER. , D. BARRATT, S. COTIN, G. FICHTINGER, P. JANNIN, N. NAVAB (editors), *Information Processing in Computer-Assisted Interventions - Proceedings of the 4th International IPCAI conference, Heidelberg, June 26, 2013.*, Springer, June 2013, vol. 7915, 111 p. , <http://hal.inria.fr/hal-00856356>

### Research Reports

- [29] H. TALBOT, F. SPADONI, M. SERMESANT, N. AYACHE, H. DELINGETTE. , *Deliverable D10.4.2*, January 2013, 22 p. , <http://hal.inria.fr/hal-00918211>

### References in notes

- [30] J. DEQUIDT, C. DURIEZ, S. COTIN, E. KERRIEN. *Towards interactive planning of coil embolization in brain aneurysms*, in "Medical Image Computing and Computer Assisted Intervention - MICCAI 2009", London,

Royaume-Uni, G.-Z. YANG, D. HAWKES, D. RUECKERT, A. NOBLE, C. TAYLOR (editors), Lecture Notes in Computer Science, Springer Berlin / Heidelberg, October 2009, vol. 5761, pp. 377-385, The original publication is available at [www.springerlink.com](http://www.springerlink.com) [DOI : 10.1007/978-3-642-04268-3\_47], <http://hal.inria.fr/inria-00430867>

- [31] G. SAUPIN, C. DURIEZ, S. COTIN, L. GRISONI. *Efficient Contact Modeling using Compliance Warping*, in "computer graphics international", Istanbul, Turquie, 2008, <http://hal.inria.fr/hal-00844039>