Activity Report 2015

Team MIMESIS

Computational Anatomy and Simulation for Medicine

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
Nancy - Grand Est

THEME
Computational Neuroscience and Medecine

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Team MIMESIS

Creation of the Team: 2015 July 01

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Other Research Topics and Application Domains:
2.4. - Therapies

Our offices are located in the Clovis Vincent building, near the IRCAD. Please do not hesitate to visit us!

1. Members

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2. Overall Objectives

2.1. Team Overview

At the end of 2011, a part of the MIMESIS team 1 moved from Lille to Strasbourg to join the newly created IHU, which is developing novel clinical technologies at the intersection of the fields of laparoscopy, interventional flexible endoscopy and interventional radiology. To develop this new discipline named "image-guided minimally invasive hybrid surgery", the IHU has established a multidisciplinary research and development program involving medical experts, scientists and industrial partners. The scientific objectives of this new team, named MIMESIS are related, but not limited to, several scientific challenges of the IHU. Over the past 4 years we have developed new approaches supporting advanced simulations in the context of simulation for training. The best example of our success in this area was certainly the work done in collaboration with the HelpMeSee foundation, leading to the creation of our start-up InSimo(read more in 7.1). We now propose to focus our research on the use of real-time simulation for per-operative guidance. The underlying objectives include patient-specific biophysical modeling, dedicated numerical techniques for real-time computation, dynamic topological representations, data assimilation and image-driven simulation. This last topic is a transverse research theme and raises several open problems, ranging from non-rigid registration to augmented reality. To pursue these directions we have started to assemble a team with a multidisciplinary background, and have established close collaborations with academic and clinical partners. One of these key partners is the ICube laboratory. We also collaborate with members of Inria Nancy, Inria Lille, Ecole Centrale de Lille, University of Luxembourg, Karlsruhe Institute of Technology, and TIMC Laboratory in Grenoble and CIMIT in Boston.

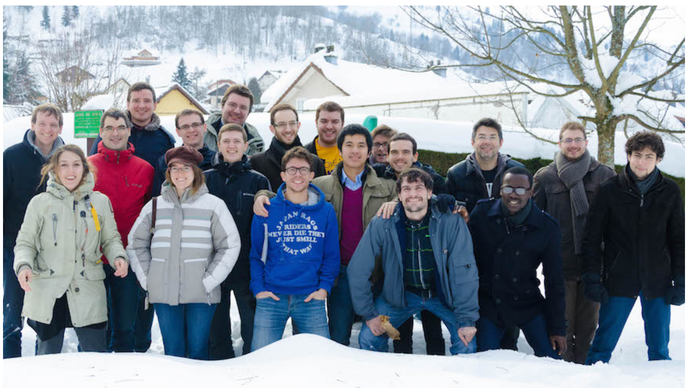


Figure 1. MIMESIS team at the annual team seminar in 2015

2.2. Challenges

The research of the MIMESIS team focuses on improving the realism and fidelity of interactive simulations of medical procedures 2. From this increase in realism, new clinical applications emerged, in particular per-operative guidance, that currently rely on imaging techniques, but could greatly benefit from our expertise in real-time numerical simulation. To reach these objectives, we addressed several challenges that lie at the intersection of several scientific domains. They include real-time biophysical models (to define new models describing soft tissue deformation or physiological phenomena such as electrophysiology), novel numerical strategies (to enable real-time computation even with the increase in complexity of future models), dynamic topological representations (to support topological changes or adaptivity of the models in areas of interest), and image-driven simulation (to link simulation with real world data such as the one available in an intra-operative context). The SOFA (Simulation Open Framework Architecture) platform, in combination with the SOFA-OR project, is used to integrate our various contributions into a series of prototypes, facilitating validation and technology transfer.

The multidisciplinary nature of our research implies that our scientific objectives span across several domains. We have identified 3 main challenges which lie at the intersection of multi-physics modeling, numerical simulation and computer vision. These challenges are summarized below:

- **Real-time patient-specific computational models**
  - Biomechanical, physiological and electrical modeling
  - Multi-model simulations
  - Validation
- **Adaptive meshing and advanced simulation techniques**
  - Multi-resolution topologies for physics-based simulation
  - Patient-specific modeling for numerical simulation
  - Numerical strategies for real-time simulation
- **Image-driven Simulation**
  - Parameter Identification / data assimilation
  - Linking image analysis and physics-based modeling

3. Research Program

3.1. Real-Time Patient-Specific Computational Models

The main objective of this scientific challenge is the modeling of the biomechanics and physiology of certain organs under various stimuli. This requires describing different biophysical phenomena such as soft-tissue deformation, fluid dynamics, electrical propagation, or heat transfer. These models help simulate the impact of certain therapies (such as cryosurgery or radio-frequency ablation), 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 (near) real-time computation and the ability to take into account for patient-specific characteristics.

An important part of our research was dedicated to the development of new **accurate models that remain compatible with real-time computation**. Such advanced models do not only permit to increase the realism of future training systems, but they act as a bridge toward the development of patient-specific preoperative planning as well as augmented reality tools for the operating room. Yet, patient-specific planning or per-operative guidance also requires the models to be **parametrized with patient-specific biomechanical data**. The objective in this area is related to the study of hyper-elastic models and their validation for a range of tissues. Preliminary work in this area has been done through two collaborations, one with the biomechanical lab in Lille (LML) with which we have a joint PhD student, and the biomechanics group from the ICube laboratory in Strasbourg on the development and validation of liver and kidney models. Another important research topic was related to model reduction through various approaches, such as Proper Generalized Decomposition (PGD). We have already established discussions with the LEGATO team at University of Luxembourg which has very good expertise in this area.

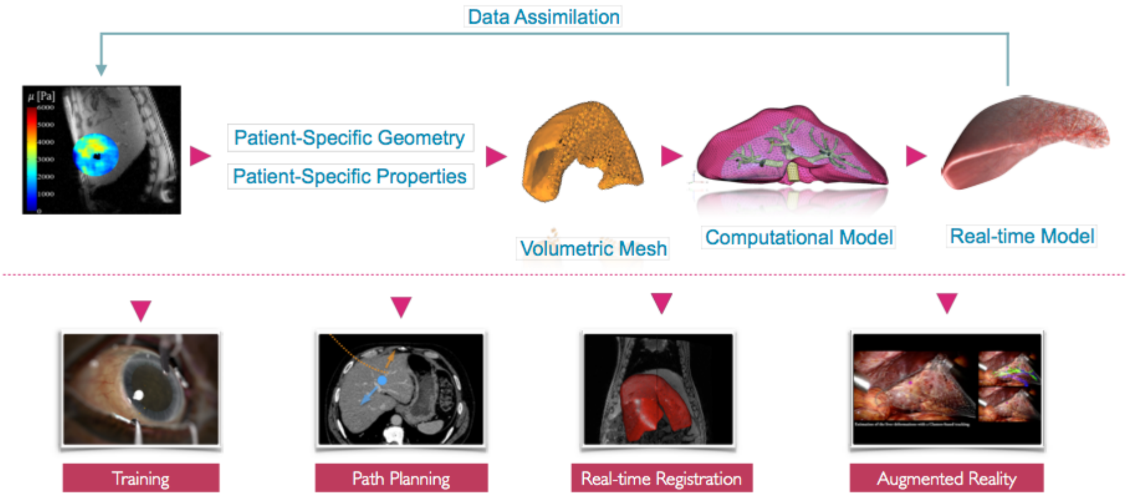
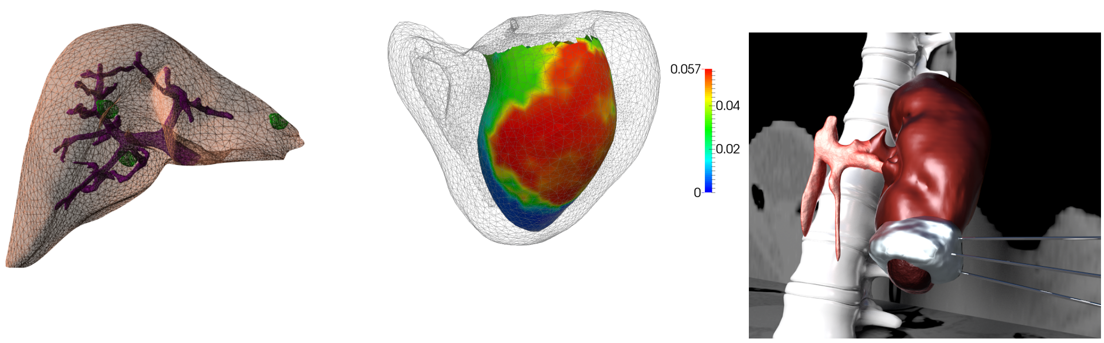


Figure 2. Objectives of the MIMESIS team: from training to intra-operative guidance, our objective is to reach accurate patient-specific simulations



(a) Patient-specific mechanical model of the liver with its vascular system extracted from Computed Tomography Angiogram, and compatible with real-time simulation

(b) Simulation of the electrical activity of a human heart from intra-operative depolarization map

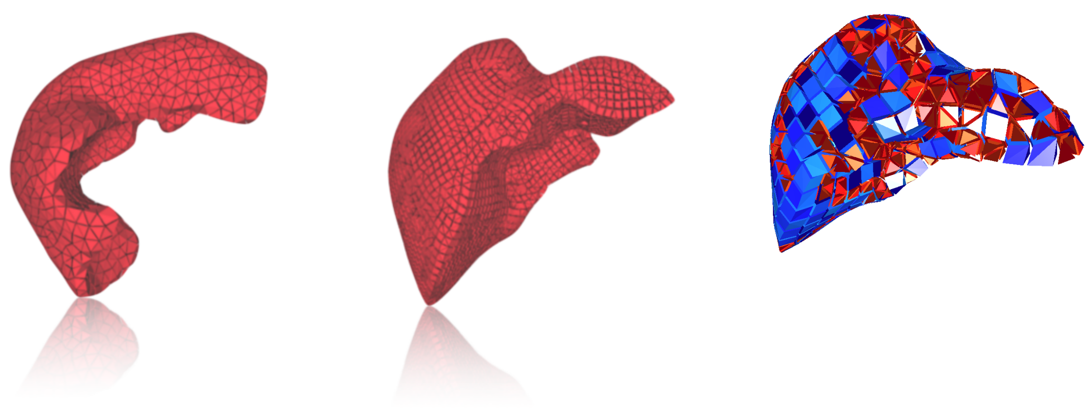
(c) Thermal evolution within a human kidney used in the context of cryoablation

Figure 3. Multi-physics and patient-specific models

We continued our work on cardiac electro-physiology simulation, with a focus on patient-specific adaptation of the model. We also studied the simulation of heat transfer and optimization problems in the context of heat diffusion. This work is a key element of the development of a planning system, such as for cryoablation procedures (Figure 3).

3.2. Adaptive Meshing and Advanced Simulation Technologies

The principal objective of this second challenge is to improve, at the numerical level, the efficiency, robustness, and quality of the simulations. To reach these goals, we followed two main directions: **adaptive meshing** to allow mesh transformations during a simulation and support cuts, local remeshing or dynamic refinement into areas of interest; and **numerical techniques**, such as asynchronous solvers, domain decomposition and model order reduction. Most simulations in the field of biomechanics, physiological modeling, or even computer graphics, are performed using finite element approaches. Such simulations require a discretization of the domain of interest, and this discretization is traditionally made of tetrahedral or hexahedral elements. The topology defined by these elements is also considered constant. The first objective of this work is to jointly develop **advanced topological operations and new finite element approaches that can leverage the use of dynamic topologies**. This covers various topics, such as simulation for cutting, tearing, fracture but also the use of multi-resolution meshes where elements are subdivided into areas where numerical errors need to be kept small [37], [38]. We also continued our work on mixed Finite Element Modeling where both tetrahedra and hexahedra can be used at the same time, allowing an ideal compromise between numerical efficiency and mesh adaptation to complex geometries (Figure 4). This research also includes the study of domain decomposition techniques and other coupling techniques for multi-domain multi-physics simulations.

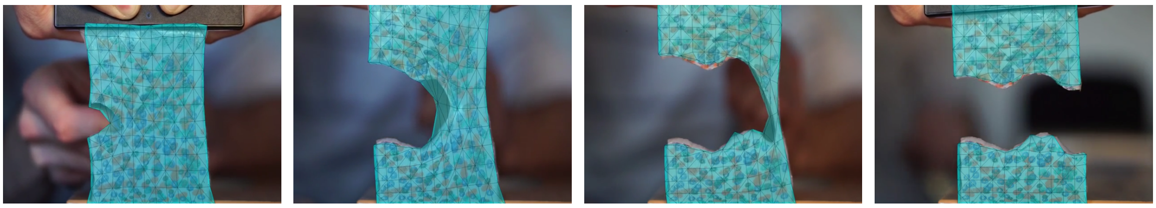


(a) Tetrahedral mesh (b) Hexahedral mesh (c) Mixed tetrahedral + hexahedral elements

Figure 4. Patient-specific volumetric meshes of the liver

3.3. Image-Driven Simulation

Image-guided simulation 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 related to image-guided therapy but the main issue consists in aligning pre-operative images onto patient per-operative data and keep this alignment up-to-date during the procedure. As most procedures deal with soft-tissues, elastic registration techniques are necessary to perform this step. Recently, registration techniques started to account for soft tissue biomechanics using physically-based methods, yet several limitations still hinder the use of image-guided therapy in clinical routine. First, as registration methods become more complex, their computation times increase, thus lacking responsiveness. Second, techniques used for non-rigid registration or deformable augmented reality only “borrow” ideas from continuum mechanics but lack some key elements (such as identification of the rest shape, or definition of the boundary conditions). Also, these registration or augmented reality problems are highly dependent on the choice of image modality and require investigating some aspects of computer vision or medical image processing. However, if we can properly address these challenges, the combination of a real-time simulation and regular acquisitions of image data during the procedure opens up very interesting possibilities by using data assimilation to better adapt the model to the intra-operative data. In the area of non-rigid registration and augmented reality, we have already demonstrated the benefit of our physics-based approaches. This was applied in particular to the problem of organ tracking during surgery (Figure 5) and led to several key publications [35], [36], [34] and awards (best paper at ISMAR 2013, second best paper at IPCAI 2014). We continued this work with an emphasis on robustness to uncertainty and outliers in the information extracted in real-time from image data. We also improved our computer vision techniques, in particular to guarantee a very accurate initial registration of the pre-operative model onto the per-operative surface patch extracted from monocular or stereo laparoscopic cameras.



(a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

Figure 5. An augmented elastic object undergoing large deformations and topological changes. The computation of the physics-based deformation, the cut detection and the topological modification of the underlying volumetric model are all performed in real-time.

The use of simulation in the context of image-guided therapy can be extended in several other ways. A direction we particularly want to address is the c**ombined use of simulation and X-ray imaging during interventional radiology procedures**. Whether it is for percutaneous procedures or catheterization, the task of the simulation is to provide a short-term (1 to 5 seconds) prediction of the needle or catheter position. **Using information extracted from the image, the parameters of the simulation can be assimilated** (using methods such as unscented Kalman filters), so that the simulation progressively matches the real data in order to reduce uncertainties. We have already started to create a flexible framework integrating the real-time soft-tissue simulation and state-of-the-art methods of data assimilation and filtering. The reduced-order stochastic filtering is a computationally efficient improvement over traditional computationally expensive **approaches which fits well the real-time and patient-specific requirements** arising from our per-operative context.

4. Highlights of the Year

4.1. Highlights of the Year

4.1.1. Translational Simulation: from pre-operative to intra-operative simulation

In recent years, an active development of novel technologies dealing with medical training, planning and guidance has become an increasingly important area of interest in both research and health-care manufacturing. With a combination of advanced physical models, realistic human-computer interaction and growing computational power, the MIMESIS team aims at bringing new solutions in order to help both medical students and experts to achieve a higher degree of accuracy and reliability in surgical interventions [26].

4.1.1.1. Pre-operative planning

In the context of cryoablation, planning the outcome of the procedure is key to ensure an optimal ablation. Cryotherapy is a rapidly growing minimally invasive technique for the treatment of certain tumors. It consists in destroying cancer cells by extreme cold delivered at the tip of a needle-like probe. As the resulting iceball is often smaller than the targeted tumor, a key to the success of cryotherapy is the planning of the position and orientation of the multiple probes required to treat a tumor, while avoiding any damage to the surrounding tissues. In order to provide such a planning tool, a number of challenges need to be addressed such as fast and accurate computation of the freezing process or interactive positioning of the virtual cryoprobes in the pre-operative image volume. To address these challenges, we developed a thermal model using the finite-element method and implemented on GPU. Our thermal model was intensively validated and specific solvers were built. From these simulations, we developed a prototype for cryotherapy planning.

4.1.1.2. Towards intra-operative guidance

Not only does the simulation bring a pre-operative support to the radiologist, but computational models can also be used intra-operatively. During the minimally-invasive liver surgery, only the partial surface view of the liver is usually provided to the surgeon via the laparoscopic camera. Therefore, it is necessary to estimate the actual position of the internal structures such as tumors and vessels from the pre-operative images. Nevertheless, such task can be highly challenging since during the intervention, the abdominal organs undergo significant deformations due to the pneumoperitoneum, respiratory and cardiac motion and the interaction with the surgical tools. Therefore, a reliable automatic system for intra-operative guidance requires fast and reliable registration of the pre- and intra-operative data. This year, we presented a complete pipeline for the registration of pre-operative patient-specific image data to the sparse and incomplete intra-operative data [21]. While the intra-operative data is represented by a point cloud extracted from the stereo-endoscopic images, the pre-operative data is used to reconstruct a biomechanical model which is necessary for accurate estimation of the position of the internal structures, considering the actual deformations. This model takes into account the patient-specific liver anatomy composed of parenchyma, vascularization and capsule, and is enriched with anatomical boundary conditions transferred from an atlas. The registration process employs the iterative closest point technique together with a penalty-based method. Following this work, we performed a quantitative assessment based on the evaluation of the target registration error on synthetic data as well as a qualitative assessment on real patient data. We demonstrated that the proposed registration method provides good results in terms of both accuracy and robustness w. r. t. the quality of the intra-operative data

4.1.2. Eurographics Award

In recent years, an active development of novel technologies dealing with medical training, planning and guidance has become an increasingly important area of interest in both research and health-care manufacturing. A combination of advanced physical models, realistic human-computer interaction and growing computational power is bringing new solutions in order to help both medical students and experts to achieve a higher degree of accuracy and reliability in surgical interventions. In our work entitled "Surgery Training, Planning, and Guidance using the SOFA Framework" [26], we presented three different examples of medical physically-based simulations implemented in a common software platform called SOFA. Each example represented a different application: training for cardiac electrophysiology, pre-operative planning of cryosurgery and per-operative guidance for laparoscopy. This paper assessed the realism, accuracy and efficiency of the simulations, as well as the potential and flexibility of the SOFA platform.

This work has been awarded at the Eurographics conference in Zurich and won the **1st prize of the Dirk Bartz Medical Prize**.

Figure 6. First Dirk Medical Prize at Eurographics 2015

4.1.3. SOFA Consortium

After ten years of development, a Consortium around the simulation platform SOFA was founded by Inria in November 2015. The MIMESIS team intensively participated in the creation of this Consortium. The objectives of this Consortium are to make the SOFA community grow and encourage contributions from new SOFA users. The Consortium should also be a way to better answer to the needs of academic or industrial partners.

A member of the MIMESIS team is now in charge of the coordination of this Consortium. A new engineer was also hired to manage the support on the SOFA forum, handle the SOFA events and communicate about SOFA Consortium. The activity of the SOFA Consortium is expected to significantly grow in the coming years.

4.1.4. Evaluation by IHU Strasbourg

Every year, research done at IHU is evaluated by a group of 15 international experts, scientists and clinicians. The 2015 report highlighted our work in the field of modeling and augmented reality: "Interestingly, besides its numerous applications for computer assisted surgery, it paves the way to build a new science of anatomy, with the establishment of innovative, "big data" based organ atlases. The program truly shows the most disruptive results. It is scientifically impressive and potentially very practical. There is no doubt that this is the domain where IHU is close to be the leading group. The program has a real strategy beyond distinct projects, and clear synergies have been identified." This report attests to our involvement within the IHU Strasbourg.

4.1.5. Science & You

Science & You is an international event about scientific mediation in the field of digital technologies. In 2015, Science & You took place in Nancy from the 1st until the 6th June 2015. Inria co-organized the event with INS2I and SIF. At this occasion, the MIMESIS team presented the results and prototypes developed in the team. This event drew a crowd and was a real success.

5. New Software and Platforms

5.1. The SOFA Framework

5.1.1. Description

SOFA [1] is an open-source software framework targeted at real-time multi-physics simulation, with an emphasis on medical simulation. The idea of SOFA was initiated by members of the MIMESIS team, strongly supported by Inria and still actively developed within the MIMESIS team. Based on C++, the SOFA engine provides many algorithms, physiological models and anatomical data, made available within a plugin architecture. With its high level of modularity, SOFA appears to be an efficient tools to benchmark and develop new medical technologies using existing algorithms.

Figure 7. Logo of the SOFA framework

The SOFA framework relies on a multi-model representation which allows for having several representations (e.g. mechanical, thermal and visual) of the same object. Those different representations are connected together through a mechanism called mapping. With these features, it is also possible to have models of very different natures interacting with each other, for instance rigid bodies, deformable objects, and fluids. CPU and GPU implementations can be transparently combined to exploit the computational power of modern hardware architectures.

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. As a 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 currently used by several industrial partners (Siemens Corporate Research, 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.

5.1.2. The SOFA Consortium

SOFA started ten years ago as an Inria collaborative research project. Now, SOFA includes many different functionalities, several companies rely on the framework as a physics engine and a large community rose over the years. To better meet the expectations of the community, Inria and the SOFA architects decided to create the SOFA Consortium in which the MIMESIS is strongly involved. The official kick-off of the Consortium took place in Strasbourg on the 25. November 2015.

The **objectives of the SOFA Consortium** can be defined as:

- Represent the identity of SOFA,
- Structure and develop the community,
- Coordinate the development of SOFA to make it always more efficient and stable.

[1] More information about SOFA at http://www.sofa-framework.org

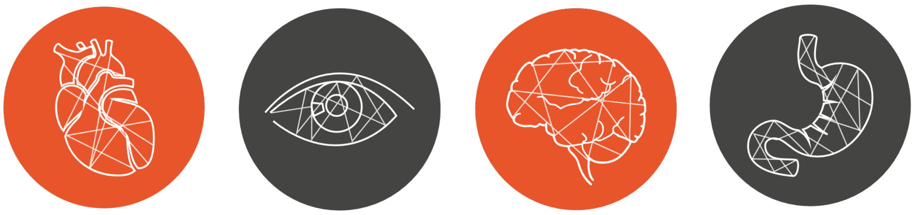


Figure 8. The SOFA Consortium was created around the SOFA platform in 2015: here are some fields of application of SOFA

The Consortium has to represent the identity of SOFA. As a consequence, the first mission of the Consortium is to promote SOFA in conferences, forums or any other event. The Consortium must present SOFA to researchers and industrials and inform about all activities around the simulation platform and the available applications. By advertising all this work, the Consortium will bring more visibility to the entire SOFA community, encourage partnership and stimulate technology transfer.

Second, the Consortium now becomes a privileged contact point for any question or request. Members, users, beginners or any interested partner can contact us. We will find the answer to their needs and thus increase the interactions outside and within the community.

Third, the Consortium is in charge of coordinating the developments made in SOFA. Through regular meetings, and bi-annual technical committee, the Consortium makes sure the development follows the road map. Moreover, the Consortium sticks to the vision of SOFA as an open-source software, that has to become more and more stable and easy to use.

Finally, a free support is provided by the Consortium on the public version of SOFA, with the help of the entire SOFA community.

6. New Results

6.1. Augmented reality for surgery

We have developed a method for real-time augmented reality of internal liver structures during minimally invasive hepatic surgery. Vessels and tumors computed from pre-operative Computed Tomography Angiograms (CTA) scans can be overlaid onto the laparoscopic view for surgery guidance. Compared to current methods, our method is able to locate the in-depth positions of the tumors based on partial three-dimensional liver tissue motion using a real-time biomechanical model. We are pursuing the development of this augmented reality system by using a better biomechanical model, and by relying on parameter optimization and additional per-operative information to further improve accuracy and robustness. In addition, more experiments, and also clinical studies are being performed to precisely measure the benefits and limitations of our approach. This work is strongly related to our involvement in the IHU Strasbourg and is tightly linked to the SOFA-OR project. Many articles were published on this topic [28], [16], [17].

6.2. Cardiac electrophysiology

Cardiac arrhythmia is a very frequent pathology that comes from an abnormal electrical activity in the myocardium. This pathology can be treated by catheterization and ablation of the malfunctionning cardiac tissue. The skills required for such interventions are still very challenging to learn, and typically acquired over several years. We first developed a training simulator for interventional electrocardiology and thermo-ablation of these arrhythmias. Based on physical models 9, this training system reproduces the different

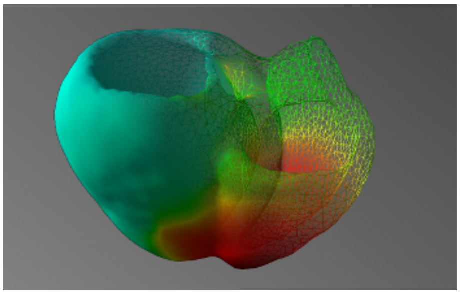


Figure 9. Electrophysiology model of the human heart

steps of the procedure, including endovascular navigation, electrophysiological mapping, pacing and cardiac ablation. Based on a scenario of cardiac arrhythmia, cardiologists assessed the interactivity and the realism of our simulation. This work has been submitted in a journal and is currently under review.

Beyond electrophysiology training, our work around the cardiac electrophysiology also consisted in personalizing our mathematical models. Using the dense electrograms recorded intra-operatively, we presented an accurate and innovative approach to personalize our model, i.e. estimate patient-specific parameters. The modeling in silico of a patient electrophysiology is needed to better understand the mechanism of cardiac arrhythmia.

6.3. Cryoablation

In 2015, we carried on the work around thermal ablation and pre-operative planning based on a thermal Finite Element Model (FEM). The cryoablation technique consists in inserting needles that freeze 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 built a simulator 10 able to place the cryoprobes and run a simulation representing the evolution of iceballs in living tissues.

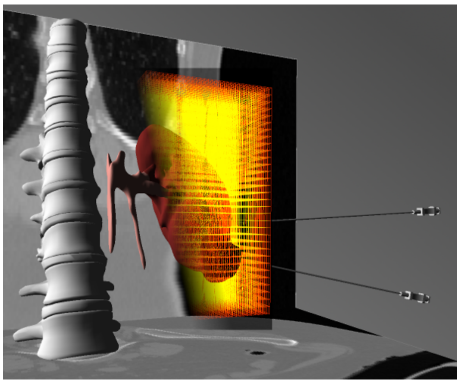


Figure 10. Cryosurgery simulation with the creation of an iceball in the kidney

6.4. 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. Both 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. Vincent Majorczyk defended his PhD [14] on this topic in 2015.

6.5. Neurosurgery

Based on an intra-operative registration method, we developed a simulation of a DBS (Deep Brain Stimulation) surgery which can help the surgeon to locate anatomical structures for a safer and a more efficient treatment. The method relies on the biomechanical model of brain shift we developed during the last years. Because some parameters of the model are unknown, we propose to estimate them with an optimization process. The cost function evaluates the distance between the model and the segmentation of pneumocephalus, the only indicator of brain shift visible on an intra-operative CT scan. In 2015, an article about the rest shape of the brain was accepted [19].

6.6. Physics-based registration algorithms

Before targeting the augmented reality for laparoscopic operations, an important step consists in solving the initial alignment problem. Given a pre-operative image of the organ (usually a CT scan) a detailed mesh is constructed. To make the information stored in this mesh available during the operation, the mesh must be registered onto the intra operative view. However, mainly due to the pneumoperitoneum, the organ has undergone important deformation between the pre-operative images acquisition and the operation. The pre-operative shape and the intra-operative shape of the organ do not correspond. Therefore a non rigid registration is required to align the mesh and the real organ. Our registration algorithms also allowed us to work on means to automatically recover boundary conditions of a patient specific liver.

We created a statistical atlas of the human liver to store the positions of the boundary conditions: the veina cava and the anchor point of the falciform ligament positions. This method was accepted at ABME in 2015 [21]. We also developed a new registration method that evolves automatically from a rigid registration to a non rigid registration to solve the initial alignment problem. The method uses some anatomical features of the liver such as the anchor point position of the falciform ligament.

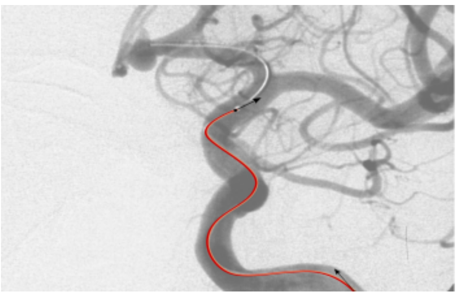


Figure 11. Detecting a catheter in interventional medical images

6.7. Radiation-less guidance during interventional radiology procedures

Significant changes have taken place over the past 20 years in medicine with the development of minimally-invasive procedures. While surgery evolved towards laparoscopy for instance, interventional radiology has become another alternative for many pathologies. Yet, some limitations remain: for percutaneous procedures, soft tissue motion, either due to breathing or deformation induced by the needle, changes the location of the target. When using image guidance, or robotic control, this remains a major obstacle. Regarding catheter-based interventions, the lack of 3D information, and extensive use of X-ray imaging to visualize the path to be followed, are among the main issues. We propose to address these different problems by developing an advanced navigation system which relies on a combination of real-time simulation and information extracted from intra-operative images to assess the current position of the needle. Such a method would have direct applications in pre-operative planning, per-operative guidance, and control for robotics. Our approach will combine advanced modeling of the device, soft tissue deformation, tissue-tool interactions, and planning algorithms 11.

6.8. Regional anaesthesia

The RASimAs project (Regional Anaesthesia Simulator and Assistant) is a European research project funded by the European Union's 7th Framework Program. It aims at providing a virtual reality simulator and assistant to doctors performing regional anaesthesia by developing the patient-specific Virtual Physiological Human models. In this project, we are in charge of developing a simulation of a needle inserted into a leg using the SOFA framework 12. We especially focused on the integration of the needle simulation into SOFA. We planned to release the first version of the simulator by January 2016.

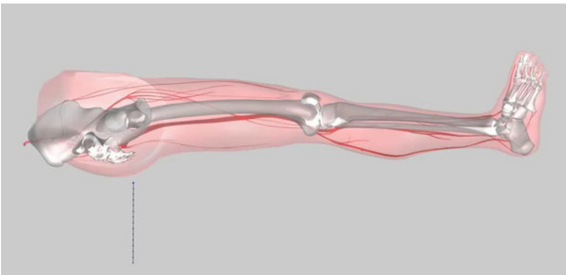


Figure 12. Needle insertion in a muscle in the context of local anaesthesia

In the context of RASimAs, we organized a coding sprint in Strasbourg in April 2015.

6.9. Training for retina surgery

Retina surgery is an increasingly performed procedure for the treatment of a wide spectrum of retinal pathologies. Yet, as most micro-surgical techniques, it requires long training periods before being mastered. To properly answer requests from clinicians for highly realistic training on one hand, and new requirements for accreditation or recertification from surgical societies on the other hand, we are developing a high-fidelity training system for retinal surgery. This simulator will be built upon our strong scientific expertise in the field of real-time simulation, and a success story for technology transfer in the field of cataract surgery simulation. Members of the consortium have a long expertise in the development of prototypes, as well as collaborations with clinical partners. The simulation system that we propose to develop is based on the Open Source simulation platform SOFA, and relies on expertise from our partners to ensure clinical and industrial relevance. This work is initially funded through the ANR project RESET which started in March 2015. A

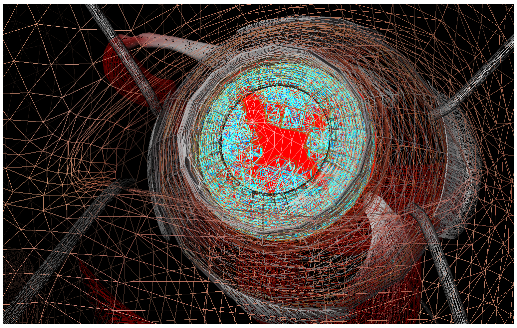


Figure 13. FEM model of the eye used in our simulation of retina surgery

first version 13 of the training system has been delivered and we made a live demonstration at the Journée Alsacienne d'Ophtalmologie.

6.10. Virtual Cutting

The simulation of cutting is a central interest in the team. We especially work on the simulation of surgical cuts 14, tearing and other separations of materials induced by surgical tools. On the one hand, we investigated the theoretical aspect: using the standard finite element method (FEM) combined with a re-meshing approach, we replace locally the current structure of the mesh in order to allow for a separation. On the other hand, we detected a separation in the motion of an object provided by a monocular video stream. With that detection, we can provide an augmented reality during the cutting and tearing of a deformable object.

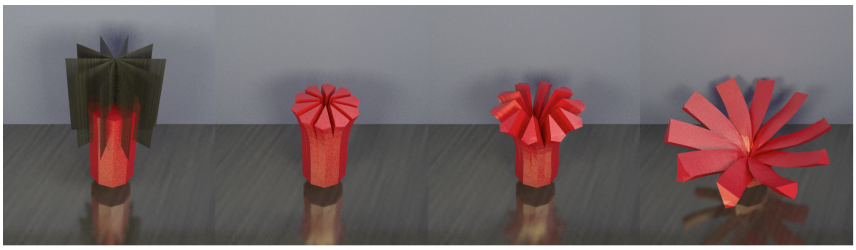


Figure 14. Our cutting algorithm in SOFA

The theoretical aspect of our work has been published in an article both at the conference Computer Graphics International CGI [24] and in the journal "The visual computer" [20]. The application in augmented reality 15 has been published at two conferences: "Augmented Reality during Cutting and Tearing of Deformable Objects", International Symposium on Mixed and Augmented Reality (ISMAR) [30].

To read more about our projects and results, please visit our website: http://mimesis.inria.fr.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

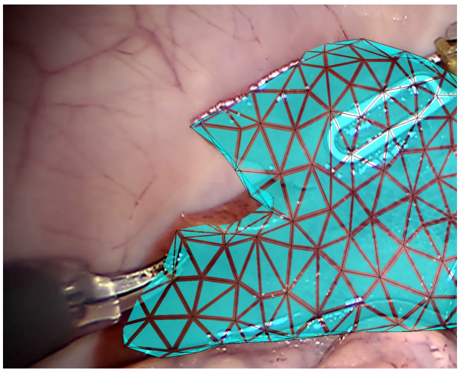


Figure 15. Augmented reality on a liver involving large deformation and cutting, i.e. topological changes

InSimo is a startup we created in January 2013, after two years of thinking, maturation and incubation. Its founding members were all former team members of the SHACRA team (our previous team): Jérémie Allard, Juan Pablo de la Plata Alcalde and Pierre Jean Bensoussan have joined the operation team, while Stéphane 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.

In the context of the SOFA Consortium, the team is also in close collaborations with:

Altran : is a global leader in innovation and high-tech engineering consulting, Altran accompanies its clients in the creation and development of their new products and services. At the occasion of the "Journée Poster", several members of the team (Rosalie Plantefève, Bruno Marques Jaime Guevara and Christoph Paulus) presented their work.

Anatoscope: is a young start-up company created in 2015 by researchers, engineers and one surgeon. We develop a software solution to automatically build 3D digital avatars based on medical images of patients. The avatars allow biomechanical simulations of the real person.

TruPhysics: develops Industry 4.0 software solutions to support manufacturing companies in development and sales processes by using a real-time and high-resolution physics simulation. We provide software that enables developers and engineers to simulate control programs, physical properties, kinematics and behavior of industrial robots, machines and assemblies.

8. Partnerships and Cooperations

8.1. National projects

8.1.1. ADT (Aide au Développement Technologique, Inria) - DynMesh

The objectives of this ADT are the coupling of SOFA, the physical simulation platform supported by Inria, and CGoGN, the mesh management library developed within the ICube lab at Strasbourg. It aims at extending the physical engine SOFA with the topological kernel of CGoGN that supports a wide variety of mesh and many local remeshing operations. The coupling of both software libraries will provide users of physical engines with new tools for the development of simulations involving topological changes like cutting, fracturing, adaptation of the resolution or improving contact management or collision detection. The impacts are numerous and will be operated directly within the MIMESIS Team, with our partners or through the establishment of new collaborations.

8.1.2. ADT - Sofa

SOFA Large Scale Development Initiative (ADT) : the SOFA project 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 4 Inria teams: ASCLEPIOS, DEFROST, IMAGINE and MIMESIS. The development program of the ADT started in 2007. This ADT ended in September 2015 and the associated contract of our SOFA engineer Marc Legendre ended at the same time.

8.1.3. ADT - SofaOR

In December 2014, a new ADT national initiative started. The objective of this ADT is twofold: first, we aim at achieving a level of quality and robustness compatible with IEC 62304 for the core of SOFA and a reduced set of components. This does not include the certification of the code itself, but rather the implementation of a comprehensive development process that will enable the certification by companies wishing to integrate this code into their systems. The second objective is to add new features specific to the needs of using intra-operative guiding tools: interoperability with equipment from the operating room, acquisition and real-time processing of full HD video streams, data assimilation and predictive filters, path planning, visualization for augmented reality, or user interfaces dedicated to the operating room.

8.1.4. ANR - IDEFI

In the IDEFI ANR, the MIMESIS team is involved in the EVEREST project which aims to develop a new generation on-line training platforms, dedicated to the theory and practice of image-guided minimally invasive surgery. A central objective is to develop a framework for the integration and the rapid spread of numerical interactive simulation systems, associated with online assessment methodologies. The IHU Strasbourg is the ANR project leader and we collaborate on the topic of virtual simulations.

8.1.5. ANR - RESET

At the end of 2014, the team has been awarded a new ANR project: RESET. This project started in March 2015. Its objective is to develop a high-fidelity training system for retinal surgery. Retina surgery is an increasingly performed procedure for the treatment of a wide spectrum of retinal pathologies. Yet, as most micro-surgical techniques, it requires long training periods before being mastered. This simulator is built upon our scientific expertise in the field of real-time simulation, and our success story for technology transfer in the field of cataract surgery simulation (MSICS simulation developed for the HelpMeSee foundation).

8.1.6. IDEX - CNRS

The aim of the project CONECT (Couplage de la rObotique et de la simulatioN mEdicale pour des proCédures auTomatisées) is to develop a robotic system for needle insertion in deformable tissues which is entirely controlled and driven by a numerical simulation. The results of this work could be extremely beneficial for medical applications, such as brachytherapy or biopsy, given the accuracy and the precision required in this kind of procedures. A first demonstration is currently under development where the needle will be inserted in a silicone gel samples. Given a non-straight predefined trajectory, our goal is to control a Mitsubishi MRV1 robot that will automatically insert a needle along the predefined path, taking into account the deformation of both the environment and the needle. The deformation of the gel is tracked with camera using the Optitrack system.

The simulation is based on real time finite element models. Based on inverse simulations, we are developing a control model that provides the kinematics of the robot such that the needle remains on the trajectory during the insertion. The activities carried out already allowed a first publication at IROS (2015) "Haptic Rendering of Hyperelastic Models with Friction" and the presentation of a poster at the conference DD23 in South Korea in july 2015 "Domain Decomposition for FE Simulation for Needle Insertion".

8.1.7. REBOAsim, Department of Defense USA

REBOA stands for Resuscitative Endovascular Balloon Occlusion of the Aorta. The objective of the REBOAsim project is to develop a low-cost miniaturized tracking and haptic interface for catheters and guidewires, meeting requirements for training and intraoperative guidance of Resuscitative Endovascular Balloon Occlusion of the Aorta (and other catheterization procedures). The second aspect of the project is the development of a computer-based simulation of REBOA procedures, allowing the training of medical personnel. This project was accepted in late 2015. In this context, we collaborate with the American Department of Defense.

8.1.8. IHU, Strasbourg

Our team has been selected to be part of the IHU of Strasbourg. This 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 a 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.

8.2. National collaborations

At the national level, the MIMESIS team collaborates with:

ICube AVR team: we are currently working with the medical robotics team on percutaneous procedures, in particular robotized needle insertion (with Prof. Bernard Bayle), and needle tracking in medical images (with Elodie Breton). We are also collaborating with Jonathan Vappou on elastography.

ICube IGG team: we have two active collaborations, one with Dr. Caroline Essert on trajectory planning (in the context of Deep Brain Stimulation) and the group involved in research on dynamic topologies. These collaborations are supported by two IHU projects: BILIKIMO and HAYSTACK.

IHU Strasbourg: as mentionned in 8.1.8, our team is one of the principal partners of the IHU Strasbourg. We developed a number of projects in close collaboration with clinicians and members of IHU.

LML Lille: is a French research laboratory (UMR CNRS 8107) part of the Carnot institute ARTS. With more than two hundreds researchers, LML focuses on the following research area : mechanical reliability and Tribology, fluid mechanics, civil engineering and soil mechanics. In 2105, Mathias Brieu from LML visited our team.

Nouvel Hopital Civil, Strasbourg: since 2014 we have been working with Prof. David Gaucher, an ophthalmologist surgeon, expert in retina surgery. This led to the submission of the ANR project RESET with started in March 2015. We also collaborate with Prof. Patrick Pessaux, a surgeon who helps us in the context of the SOFA-OR project.

R&D team at IRCAD: the computer science group at IRCAD has been involved in segmentation, 3D reconstruction and augmented reality for abdominal surgery since the 2000. An important activity on simulation also took place and led to the creation of a start-up company, Digital Trainers. Currently, the main activities are centered around augmented reality, registration, and medical imaging.

TIMC, Grenoble: this large research group has a strong background in computer-aided surgery, medical imaging, registration, statistical and bio-mechanical modeling. We have regular interactions with this various members of this group. We are collaborating with Yohan Payan (DR CNRS) on the modeling and simulation of the brain shift. A common PhD thesis started on that topic in late 2014. Other areas of interest are in the field of advanced soft tissue modeling and computer aided surgery,

8.3. Inria collaborations

Within Inria, the MIMESIS team collaborates with:

ASCLEPIOS: although the core activities of team are in the field of medical image analysis, it also has a strong expertise in physics-based simulation of the heart. We collaborated on the development of an electro-mechanical model of the heart, and on some core components of SOFA. We collaborate with the ASCLEPIOS team on the development of the SOFA framework and on the development of a simulation system for radio-frequency ablation in the case of cardiac arrhythmia,

DEFROST: the team imagines future robots which don't need to be "rigid" but made of complex deformable structures, composed of stiff and soft regions, close to organic materials that can be found in nature. Soft robotics opens very attractive perspectives in terms of new applications, reduction of manufacturing costs, robustness, efficiency and security. It could constitute a great jump in robotics in the following years. We continue to interact with the team in Lille given our common research background. A joint article of constraint-based haptic modeling has already been submitted.

IMAGINe: the team has a general focus on animation and simulation of natural objects. We essentially collaborate with Prof. François Faure on real-time finite element techniques, collision detection and contact response (which led to a SIGGRAPH paper) and the development of SOFA,

MAGRIT: their research field is computer vision, with a focus on augmented reality applications. The team is also fairly involved in computer-based solutions for the planning or the simulation of interventional radiology procedures, with a strong collaboration with the CHU in Nancy. We collaborate with the MAGRIT team in the area of interventional radiology and augmented reality. A common PhD thesis, whose subject was to develop implicit representations of anatomical structures such as blood vessels or aneurysms, was defended in 2013. Another joint PhD thesis was defended in January 2015 on the topic of non-rigid augmented reality and combined the computer vision expertise of MAGRIT with our expertise on real-time simulation and biomechanical modeling.

8.4. European Initiatives

8.4.1. RASimAs

2015 was the second year of the RASimAs project (STREP project funded under FP7) during which we developed new models of the biomechanics of the leg and arm, as well as the simulation of the insertion of the anaesthesiology needle. Regional anaesthesia has been used increasingly during the past four decades. This is due 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 MIMESIS 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.

See http://rasimas.imib.rwth-aachen.de for more details.

In the context of the RASimAS project, we collaborate with the company:

- **SenseGraphics**: develops next generation medical simulator software for a wide range of surgical procedures. It is used in simulators for training surgeons in various fields such as robotic surgery, eye surgery, dentistry, ultrasound interpretation and anesthesia. The simulators combine the latest technologies in real-time graphics rendering as well as advanced force feedback to allow the surgeons to have an experience that is as close to reality as possible.

With the RASimAS project, we also collaborate with: the University Hospital Aachen, RWTH Aachen University, Bangor University, University College Cork, Universidad Rey Juan Carlos, Foundation for Research and Technology Hellas, Zilinska univerzita v Ziline, Katholieke Universiteit Leuven and the Stiftelsen Sintef.

8.5. International Initiatives

8.5.1. Inria International Partners

At the international scale, the MIMESIS team collaborates with:

CIMIT, Boston: we are restarting our interactions on interventional radiology simulation, in particular the design and development of a hardware interface for tracking catheters and guidewires. A joint proposal to the DoD has been submitted to this end.

Harvard Biorobotics lab, Cambridge: this group focuses on the role of sensing and mechanical design in motor control, in both robots and humans. This work draws upon diverse disciplines, including biomechanics, systems analysis, and physiology. We started a collaboration on inverse problems for identifying optimal areas of cardiac ablation using our work on electro-mechanical modeling of the heart. Other areas of collaboration are planned, such as cardiac valve interactions with blood flow.

Humanoid and Intelligence Systems Lab, Karlsruhe Institute of Technology: we started a collaboration with Dr Stefanie Speidel and Dr. Stefan Suwelack on the topics of real-time soft tissue modeling and laparoscopic augmented reality.

Institute of Computer Science, Masaryk University, Czech Republic: we have an extensive collaboration with Igor Peterlik at the ICS, leading to 7 publications over that past 18 months. This collaboration covers the fields of non-rigid registration, augmented reality and haptics.

Interactive Graphics and Simulation, Innsbruck: the IGS group in Innsbruck is a continuation of a group led at ETH by Matthias Harders. Its scientific focus is on physically-based simulation, computer haptics, and to a limited extent, augmented reality. The main application area is the medical domain.

Surgical Planning Lab, Boston: this research laboratory at Brigham and Women's Hospital has a large expertise in the analysis of diagnostic data using computational image analysis. We know this group very well, in particular in the field of Deep Brain Stimulation and through their work on Open Source solutions for computer aided surgery. We are regularly interacting with them on the development of a version of SOFA dedicated to the operating room.

SINTEF, Norway: we are currently collaborating with SINTEF in the context of the european project RASimAs, and also on other aspects, such as the creation of anatomically correct and accurate datasets from patient-specific data. We are also discussing future collaborations in the context of hepatic surgery simulation and augmented reality (we have jointly written a H2020 proposal on this topic).

Team Legato, University of Luxembourg: since last year we have active discussions with Prof. Stéphane Bordas on real-time soft tissue cutting simulation. This has already led to a journal article in Media [33] and a co-supervision of a post-doctoral fellow.

8.6. International Research Visitors

8.6.1. Visitors

In 2015, MIMESIS invited several visitors:

- Jim Ueltschi (founder of the HelpMeSee non-profit organization)
- Karol Miller (Winthrop Professor, School of Mechanical and Chemical Engineering, The University of Western Australia)
- Stéphane Bordas (LEGATO team, Luxembourg)
- Karel van Gelder (Product manager, MOOG, Amsterdam)
- Alexandre Krupa (Inria, Rennes)
- Mathias Brieu (Laboratoire de Mécanique, Ecole Centrale Lille)

8.6.2. Internships

In 2015, the MIMESIS welcomed two international interns (for 6 months):

Santiago Camacho, Universidad de Buenos Aires, worked on "Improvement of Visualization Tools for Augmented Reality Applications"

Sabrina Izcovich, Universidad de Buenos Aires, worked on "Quadratic Tetrahedron Element for FEM simulations".

8.6.3. Visits to International Teams

8.6.3.1. Explorer programme

This year, Hugo Talbot obtained an Inria Explorer grant in the context of a partnership with the Harvard BioRobotics Laboratory from Harvard, Cambridge. The Explorer programme covered the one-month visit (June 2015). This visit allowed to discuss about our respective work around simulation, especially concerning simulation in the field of cardiology. This was also the opportunity to establish several academic and industrial contacts in the United States. Hugo Talbot namely visited:

- **Thermedical**: is a company developing a new generation of radio-frequency catheters.
- **Center of Medical Simulation**: is a simulation center focusing on training based on mannequins.
- **SimQuest**: is a company developing simulation technologies for medicine, very close to the research topic of our team.
- **Surgical Planning Laboratory** (Brigham and Womens' Hospital) is a research center very close to the clinics and working mainly on medical imaging, but also interested in the medical simulation.
- **CIMIT**: is a research center developing mannequins for training.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events selection

9.1.1.1. Reviewer

Stéphane Cotin made reviews for the following conferences:

VRIPHYS

VCBM (Visual Computing in Biology and Medicine)

and MICCAI.

David Cazier made reviews for the conference:

Computer Graphics International (CGI)

Nazim Haouchine made reviews for the conference:

International Symposium on Biomedical Imaging

9.1.2. Journal

9.1.2.1. Reviewer - Reviewing activities

Stéphane Cotin made reviews for:

the Medical Image Analysis journal.

Hadrien Courtecuisse made reviews for:

IEEE Haptics Symposium,

Transactions on Haptics,

The Visual Computer,

Medical & Biological Engineering & Computing.

David Cazier made reviews for:

the Computer-Aided Design (CAD) journal,

the Visual Computer journal.

Huu Phuoc Bui made reviews for:

the Computational Mechanics journal,

Nazim Haouchine made reviews for the journal:

IET Computer Vision

Rosalie Plantefeve made reviews for the journal:

IJCARS

9.1.3. Invited talks

Stéphane Cotin has been invited speaker:

keynote lecture at "Open Your Mind" seminar series, ECAM (Paris, France),

keynote lecture at the 10th MICCAI Computational Biomechanics Workshop (Munich, Germany)

keynote lecture at Visual Computing in Biology and Medicine (Chester, UK),

invited talk at HCST Medical Robotics (Tel Aviv, Israel),

invited speaker at the International Conference on Augmented and Virtual Reality (Salento, Italy).

Hadrien Courtecuisse has been invited speaker:

in the legato team at the Computational Mechanics department of the Luxembourg University July 2015,

at SINTEF Technology and Society Medical Technology Department. Trondheim, Norway,

at HCST Medical Robotics symposium. Tel-Aviv, Israel.

Hugo Talbot has been invited speaker:

at the Karlsruhe Institute of Technology in July 2015, Germany.

at the AVR Salento conference in October 2015, Italy.

Figure 16. Presentation of SOFA at the conference AVR Salento in Lecce (Italy)

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Stéphane Cotin was in charge of the following course:

Course on real-time biomechanical simulation at École Catholique d'Arts et Métiers (Paris, France)

Hadrien Courtecuisse was in charge of the following courses:

Master TIC-Santé. Télécom Physique Strasbourg : Real time simulation (30h)

Master IRMC : (10 h) Real time simulation

David Cazier was in charge of the following course:

Licence : Web technologies and programming, 96hTD, DUT2, Université de Strasbourg, France

9.2.2. Supervision

Stéphane Cotin supervised

PhD defended (in co-direction with DEFROST team): Vincent Majorczyk, Modeling of the interactions between deformable bodies and fluids in the context of medical simulation in real-time, 1/01/2010 - 28/04/2015

PhD defended : Nazim Haouchine, Image-guided Simulation for Augmented Reality during Hepatic Surgery, 1/10/2011 - 16/01/2015

PhD in progress : Christoph Paulus, Modélisation et simulation temps-réel pour la prise en compte des changements topologiques dans les tissus mous, 1/01/2014

PhD in progress : Rosalie Plantefeve, Augmented reality and numerical simulations for resection of hepatic tumors, 1/01/2014

Hadrien Courtecuisse supervised:

PhD in progress: Yinoussa adagolodjo, Coupling between robotics and medical simulation for automated procedures in the scope of the CONECT project. University of Strasbourg, 1/02/2015

PhD in progress (in co-direction with the TIMC laboratory): Fanny Morin, Non linear simulation for intraoperative guidance for neurosurgery. Université de Grenoble, 1/10/2014

Internship : Asmaa Ait Hadouch, from Telecom Physique Strasbourg. Topic: communication protocol between Sofa, Mitsubishi MRV1A robot, and optitrack system fot the project CONECT, 1/06/2015 - 31/08/2015

David Cazier supervised:

PhD defended: Thomas Pitiot, Multiresolution tools for the management of interaction in real time simulations (Outils multirésolutions pour la gestion des interactions en simulation temps-réel), Université de Strasbourg, 17/12/2015

PhD in progress : Christoph Paulus, Modélisation et simulation temps-réel pour la prise en compte des changements topologiques dans les tissus mous, 1/01/2014

Frédérick Roy and Rosalie Plantefeve co-supervised:

Internship : Santiago Camacho, from Universidad de Buenos Aires. Topic: software development around visualization for augmented reality applications, 1/07/2015 - 1/12/2015

Hugo Talbot supervised:

Internship : David John, from Karlsruhe Institute of Technology. Topic: research around simulation of thermal effect in living tissues, development of specific solvers, 1/11/2015

Christoph Paulus supervised:

Internship : Sabrina Izcovich, from Universidad de Buenos Aires. Topic: research around second-order finite element methods and simulation of cutting, 1/09/2015

9.2.3. Juries

Stéphane Cotin was part of the following juries:

PhD defense: Mariem Gargouri Osman : "Caractérisation des usagers de la route par imagerie médicale : Extraction fine des paramètres géométriques des côtes à partir de volumes d'images CT", 06/2015 (President)

PhD defense: Vincent Majorczyk "Modélisation des interactions entre solides déformables et films fluides pour la simulation médicale temps-réel", 04/2015 (Supervisor)

PhD defense: Chloe Audigier "Modélisation de l'ablation radiofreéquence pour la planification de la résection de tumeurs abdominales", 10/2015 (President)

PhD defense: Pierre Chantereau "Caractérisation biomécanique et modélisation histologique des mécanismes de vieillissement et d'endommagement du système pelvien", 07/2015 (Reviewer)

David Cazier was part of the following juries:

PhD defense: Vincent Majorczyk, Modeling of the interactions between deformable bodies and fluids in the context of medical simulation in real-time, 4/11/2015 (Reviewer)

PhD defense: Evans Bohl, Modélisation de fruits de leurs structures internes et de leurs défauts, Université de Poitiers, 4/11/2015 (Reviewer)

PhD defense: Kevin Jordao, Interactive design of crowd animations in large environments, 21/12/2015 (Reviewer)

9.3. Popularization

9.3.1. IHU Scientific Days

At the occasion of the 4 IHU Scientific days in 2015, the MIMESIS took part and organized several meetings, presentation and discussions around simulation in medicine.

9.3.2. Journée Francaise de Radiologie, JFR

The MIMESIS team was part of the JFR 2015 event in Paris on the 16 and 17th October 2015. Hugo Talbot presented the work and the projects achieved by the team.

Figure 17. Our booth in the RII Health 2015 in Bordeaux

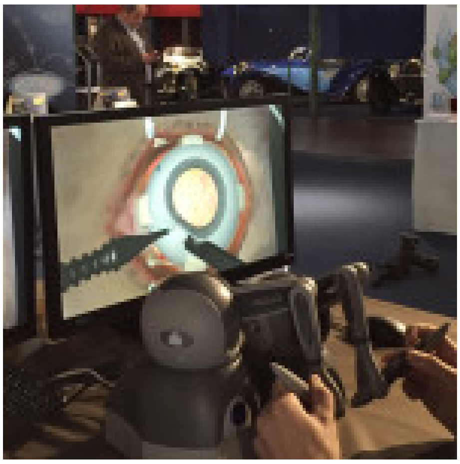


Figure 18. Rémi Bessard presenting our simulation at JAO 2015

9.3.3. Rencontre Inria Industrie, RII

Hugo Talbot presented the SOFA framework and our current work during the "Rencontre Inria Industrie" 2015 which took place in Bordeaux. We had many nice discussions and feedback about SOFA.

9.3.4. Journée Alsacienne d'Ophtalmologie, JAO

In collaboration with the ophthalmologist Pr. Gauchet, several members of the team (Rémi Bessard, Bruno Marques and Stéphane Cotin) participated at the JAO (Journée Alsacienne d'Ophtalmologie) on the 28th and 29th of November 2015. They presented our prototype simulator for retinal surgery.

9.3.5. Talk at Université Paris Descartes

On the 4th of December, Stéphane Cotin was invited as a speaker to the BME seminar at University Paris Descartes. His talk was entiteled "patient safety through real-time numerical simulation".

9.3.6. Talk at MEDinISRAEL

Stéphane Cotin and Hadrien Courtecuisse were invited at the MedinISRAEL 2015 conference which took place in Tel Aviv. This event was the opportunity for the team to present our work to the community. Moreover, the university from Tel-Aviv strongly supports new collaborations with French laboratory.

Figure 19. Presentation of Stéphane Cotin at MEDinISRAEL 2015

9.3.7. Science & You

In Nancy, Science & You opened its doors on the 2nd of June. The MIMESIS team participated on June 5th and 6th to present some of our simulations. This was a great success and a large audience came to our booth.

9.3.8. Pitch at B.E.S.T. Symposium

B.E.S.T. (Business Engineering and Surgical Technologies) is an original education program proposed by the IHU Strasbourg dedicated to undergraduate, graduate and postgraduate students in medicine, engineering and management. In the context of the B.E.S.T. Symposium, Hugo Talbot presented a concept of start-up about medical training based on simulation which any student could afford. Rosalie Plantefeve also attended the B.E.S.T. Symposium.

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Major publications by the team in recent years

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