Activity Report 2016

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

Table of contents

Team MIMESIS

Creation of the Team: 2015 July 01

Keywords:

Computer Science and Digital Science:

2.5. - Software engineering
3.1.1. - Modeling, representation
3.1.4. - Uncertain data
3.2.2. - Knowledge extraction, cleaning
5.1. - Human-Computer Interaction
5.3.4. - Registration
5.4.4. - 3D and spatio-temporal reconstruction
5.4.5. - Object tracking and motion analysis
5.6. - Virtual reality, augmented reality
6.1.1. - Continuous Modeling (PDE, ODE)
6.1.5. - Multiphysics modeling
6.2.8. - Computational geometry and meshes

Other Research Topics and Application Domains:

2.4. - Therapies
2.4.3. - Surgery
2.6. - Biological and medical imaging
2.7. - Medical devices
2.7.1. - Surgical devices

1. Members

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Bruno Marques [Inria]
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Lionel Untereiner [Inria]

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David John [Inria, Intern, until Jan 2016]
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2. Overall Objectives

2.1. Team Overview

At the end of 2011, a part of the SHACRA team moved from Lille to Strasbourg to join the newly created IHU institute, whose main objective is to develop novel clinical technologies at the crossroads of laparoscopic surgery, flexible endoscopy and interventional radiology. Similar institutes have been created in the past decade around the world, with the same global objective: create a synergy between clinicians and scientists to develop new technologies that can redefine healthcare, with a strong emphasis on clinical translation.

The scientific objectives of our new team, MIMESIS, are related to this ambitious objective. Over the past 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.

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**, data assimilation and **data-driven simulation**. This last topic is a transversal research theme and raises several open problems, ranging from non-rigid registration to augmented reality.

2.2. Challenges

The core research topics of the MIMESIS project-team essentially aim at improving the realism and fidelity of interactive simulations of medical procedures. This increase in realism makes it possible to envisage new clinical applications, 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 have identified several challenges that lie at the intersection of several scientific domains. They include the **modeling of complex anatomical environments** (to define new models describing soft tissue deformation or address coupled multi-physics problems), **novel numerical strategies** (to enable real-time computation even with the increase in complexity of future models), and **data-driven simulation** (to link simulation with real world data such as intra-operative images).

The SOFA framework is used to integrate our various contributions as a means to facilitate validation and technology transfer.

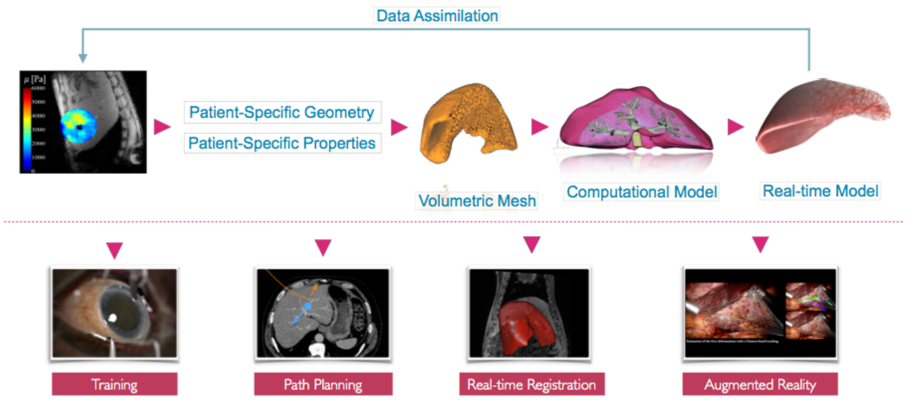

Figure 1. Patient-specific simulations: from training to intra-operative guidance

3. Research Program

3.1. Modeling of complex anatomical environments

Objectives:

- Coupled and multi-physics models & Non-linear and composite models
- Smooth and high-order FEM
- Hierarchical and heterogeneous representations

Milestones:

- Composite structures (e.g. vascularized organs)
- Integration of hyper-elastic materials and higher-order elements
- Combined behaviors (e.g. electro-mechanical model of the heart)

A central objective of this challenge is the modeling of the biomechanics and physiology of organs under various stimuli. This requires to describe different biophysical phenomena such as soft-tissue deformation, fluid dynamics, electrical propagation, or heat transfer. These models will help simulate the impact of different therapies (such as cryosurgery, radio-frequency ablation, surgical resection), but also represent the behavior of complex organs such as the brain, the liver or the heart (Figure 2).

A common requirement across these developments is the need for (near) real-time computation and the ability to adapt to patient-specific characteristics. Simulating such complex surgical environments involves the coupled use of composite models coming with their own discretizations that differ in terms of topology and dimension. This requires methods involving hierarchical or multi-resolution models that provide an inherent solution for the coupling of such heterogeneous representations. Another, related, objective is to study methods able to locally adapt the mesh resolution (when using an FEM approach) to the need of the simulation or to simulate the propagation of fractures during soft tissue tearing.

An important part of our research is dedicated to the development of new accurate models that remain compatible with real-time computation. Such advanced models not only permit to increase the realism of future training systems, but also 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

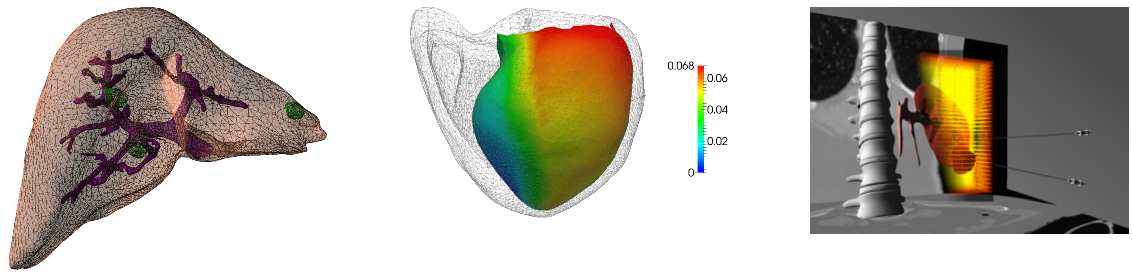

Figure 2. Left: patient-specific liver model with its vascular system. Middle: patient specific depolarization times. Right: cryoablation in the kidney.

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), and the biomechanics group from the ICube laboratory in Strasbourg on the development and validation of liver and kidney models.

Another important research topic will be related to model reduction through various approaches, such as Proper Generalized Decomposition (PGD) or modal analysis. We are currently collaborationg with the Legato team at University of Luxembourg which has good expertise in this area. Similar approaches, such as the use of Krylov spaces, have already been studied in our group recently.

We are transitioning from our work on cardiac electro-physiology simulation to the modeling of the electrical conduction in soft tissues as well as optimization problems in the context of heat diffusion. This is a key element of the development of both planning and guidance systems for percutaneous procedures, such that an optimal therapeutical effect can be reached.

3.2. Numerical methods for real-time simulation

Objectives:

- Numerical solution of systems of equations
- Acceleration and optimization with parallel computing
- Context-aware discretization and adaptive (re)meshing for cuts and fractures
- Advanced constraints: Interaction, multi-body contacts - Collision detection

Milestones:

- Simulation of cutting, fracture and tearing
- Finite element simulation using adaptive meshing
- Mixed or hybrid finite element methods

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 essentially rely on two approaches: **adaptive meshing** to allow mesh transformations during a simulation and support cuts, local remeshing or dynamic refinement in areas of interest; and **numerical techniques**, such as asynchronous solvers, domain decomposition and model order reduction (Figure 3).

Typically, the simulations in the field of biomechanics, physiological modeling, or even computer graphics, employ techniques based on the finite element method. 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. In particular we focus our research on multi-resolution meshes where elements are subdivided in areas where numerical errors need to be kept small [25], [27].

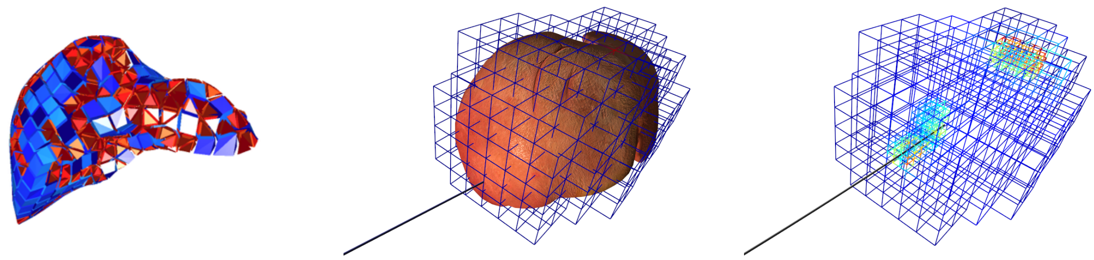

Figure 3. Left: Patient-specific mixed (tetrahedral + hexahedral) mesh of the liver. Middle: liver surface embedded into an hexahedral mesh. Right: dynamic subdivision of the mesh based on geometrical and mechanical constraints.

Once the problem, as defined in the previous challenge, has been discretized, we need to solve a large system of linear or nonlinear equations. In both cases, it is necessary to employ numerical solvers repeatedly to construct the solution representing the state of the simulated system. In the past years, we have contributed to this topic through our work on asynchronous preconditioning [19]. We would like to pursue this area of research exploiting the relevant advances in hierarchy-based topologies (e.g. the multi-grid methods). We will also consider advanced non-linear solvers which are necessary for correct resolution of hyper-elastic models and composite models.

Finally, to improve computational times from a programming stand-point, we have started a collaboration with the CAMUS team at Inria. This collaboration aims at using smart code analysis and on-the-fly parallelism to automatically speed-up computation times. In a typical scenario, the modeled organ or tissue is surrounded by its environment represented by other organs, connective tissues or fat. Further, during the intervention, the tissues are manipulated with instruments. Therefore, the interaction will also be an important aspect of our research. We have already developed methods for modeling of advanced interactions between organs, tissues and tools [24] [20]. We will continue exploiting novel methods such as partial factorization [28] and integrate our approach with other techniques such as augmented Lagrangian.

3.3. Data-driven simulation

Objectives:

- Stochastic filtering
- Inverse modeling
- Parametrization and estimation of the boundary conditions
- Validation and experimental assessment

Milestones:

- Non-rigid registration using biomechanical models
- Augmented reality for hepatic surgery
- 3D-2D real-time fusion for vascular surgery

Image-guided simulation has been a recent area of research in our team. We believe it 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 the patient 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.

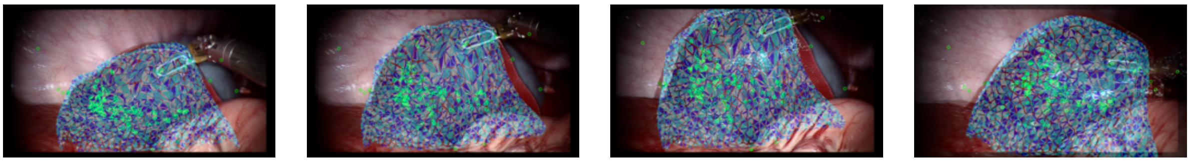

Figure 4. Real-time deformation of a virtual liver according to tissue motion tracked in laparoscopic images.

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 to investigate 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 intra-operative data, not limited to image-based information.

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 4) and led to several key publications [22] [23] [21] and awards (best paper ISMAR 2013, second best paper at IPCAI 2014). We continue this work with an emphasis on robustness to uncertainty and outliers in the information extracted in real-time from image data and by improving upon our current 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. This work will finally benefit from advances in the challenges listed previously, in particular real-time hyper-elastic models of behavior.

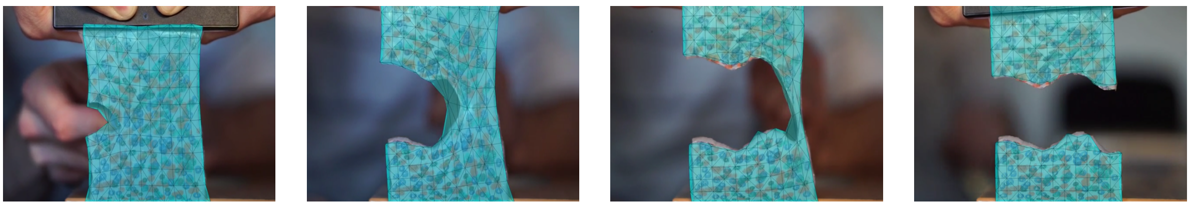

Figure 5. An augmented elastic object is torn. The cut is detected and applied to the virtual model in real time.

The use of simulation in the context of image-guided therapy can be extended in several other ways. A direction we are addressing is the combined 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.

4. New Software and Platforms

4.1. Simulation Open Framework Architecture

Keywords: Real time - Multi-physics simulation - Medical applications

Description: SOFA is an Open Source framework primarily targeted at real-time simulation, with an emphasis on medical simulation. It is mostly intended for the research community to help develop new algorithms, but can also be used as an efficient prototyping tool. Based on an advanced software architecture, it allows : the creation of complex and evolving simulations by combining new algorithms with algorithms already included in SOFA, the modification of most parameters of the simulation (deformable behavior, surface representation, solver, constraints, collision algorithm, etc.) by simply editing an XML file, the building of complex models from simpler ones using a scene-graph description, the efficient simulation of the dynamics of interacting objects using abstract equation solvers, the reuse and easy comparison of a variety of available methods.

URL: http://www.sofa-framework.org

5. New Results

5.1. Augmented Reality for Hepatic Surgery

Participants: Rosalie Plantefève, Bruno Marques, Frederick Roy, Nazim Haouchine, Igor Peterlik, Stéphane Cotin.

Liver cancer is the 2nd most common cause of cancer death worldwide, with more than 745,000 deaths from liver cancer in 2012. When including deaths from liver cirrhosis, the toll reaches nearly 2 million people worldwide. Today, surgical tumor ablation remains the best treatment for liver cancer.To localize the hepatic tumors and to define the resection planes, clinicians rely on pre-operative medical images (obtained with computed tomography scanner or magnetic resonance imaging). However, the liver lesions and vascular system are difficult to localize during surgery. This may lead to incomplete tumor resection or haemorrhage.

We provide surgeons with an augmented view of the liver and its internal structures during surgery to help them to optimally resect the tumors while limiting the risk of vascular lesion. Therefore, an elastic registration method to align the pre-operative and intra-operative data has been developed [26]. This method, which uses a biomechanical model and anatomical landmarks, was designed to limit its impact on the clinical workflow and reaches a registration accuracy below the resection margin even when the liver is strongly deformed between its pre-operative and intra-operative state. This registration algorithm has been integrated into a software, SOFA-OR, to conduct the first clinical tests.

5.2. Augmented Reality for Mini-Invasive Surgery

Participants: Nazim Haouchine, Lionel Untereiner, Frederick Roy, Igor Peterlik, Stéphane Cotin.

We have addressed the ill-posed problem of initial alignment of pre-operative to intra-operative data for augmented reality during minimally invasive hepatic surgery. This problem consists in finding the rigid transformation that relates the scanning reference and the endoscopic camera pose, and the non-rigid transformation undergone by the liver with respect to its scanned state. Most of the state-of-the-art methods assume a known initial registration.

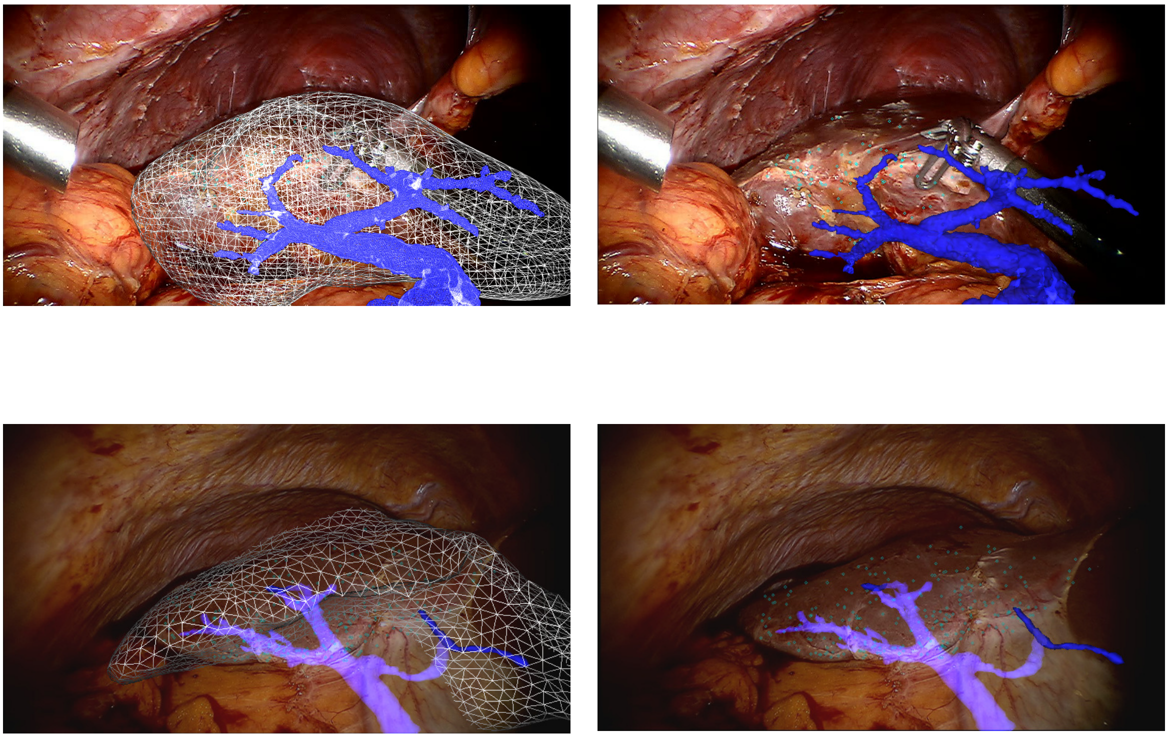

Figure 6. Non-rigid registration between intra-operative and pre-operative data. The overlay of the liver and its vascular network help the surgeon during the operation.

We have proposed in [16] a method that permits to recover the deformation undergone by the liver while simultaneously finding the rotational and translational parts of the transformation. Our formulation considers the boundaries of the liver with its surrounding tissues as hard constraints directly encoded in an energy minimization process. We performed experiments on real in-vivo data of human hepatic surgery and synthetic data, and compared our method with related works (Figure 7).

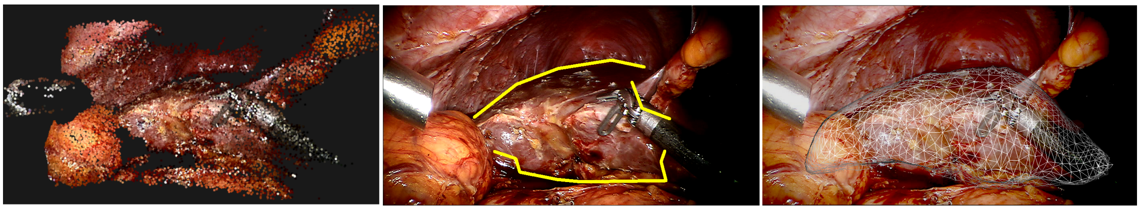

Figure 7. Left: a 3D map is reconstructed from the intra-operative view. Middle: The contours of the liver are extracted. Right: They are used as constraint to pilot a biomechanical model.

5.3. Detecting topological changes during non-rigid registration

Participants: Christoph Paulus, David Cazier, Stéphane Cotin.

Augmented reality has shown significant promise in overcoming certain visualization and interaction challenges in various domains such as medicine, construction, advertising, manufacturing, and gaming. Despite the promise of augmented reality and its successful application to many domains, significant research challenges remain. Among these challenges is the augmentation of non-rigid structures that can undergo topological changes, such as fracture, tearing or cutting. This is for instance the case in minimally invasive surgery, which has gained popularity and became a well-established procedure thanks to its benefits for the patient, in particular with shortened recovery times.

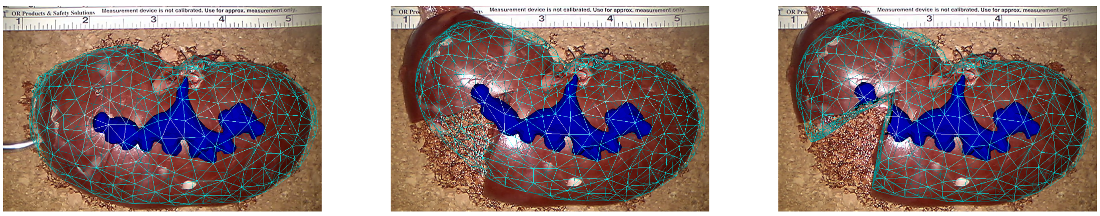

Figure 8. Left: A kidney whose internal structures have been scanned and segmented is cut and deformed. Middle: Standart methods do not detect the cut. Right: Our method detects the cut and applies it to the virtual model.

Current methods dealing with non-rigid augmented reality only provide an augmented view when the topology of the tracked object is not modified, which is an important limitation. We solve this shortcoming by introducing a method for physics-based non-rigid augmented reality [11]. Singularities caused by topological changes are detected by analyzing the displacement field of the underlying deformable model. These topological changes are then applied to the physics-based model to approximate the real cut. All these steps, from deformation to cutting simulation, are performed in real-time. This significantly improves the coherence between the actual view and the model, and provides added value.

5.4. Augmented Reality for Vascular Surgery

Participants: Raffaella Trivisonne, Igor Peterlik, Hadrien Courtecuisse, Stéphane Cotin.

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. Regarding catheter-based interventions, the lack of depth perception in projective grey-scale images, and the extensive use of X-ray imaging to visualize the instrument and the anatomy through which it must be inserted, 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 catheter. Such a method would have direct applications in endovascular procedures allowing for an enhanced view of the operating field, both in term of 3D perception and quality of the images. Our approach combines advanced modeling of the device, 2D-3D registration and constraint-based simulation.

We have developed a method [18] based on constraint-based simulation allowing for the enhancement of fluoroscopic images with a 3D real-time catheter insertion and 3D vessel visualization. Our method relies mainly on image features, without the need of any information about the surrounding 3D vasculature, nor does it require any tracking device (Figure 9).

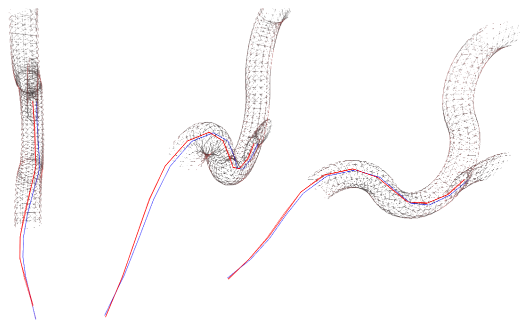

Figure 9. A 3D catheter reconstruction (red) and the real catheter (blue).

5.5. Image analysis for the characterization of cell mobility

Participant: Igor Peterlik.

The complex behaviour of motile cells plays a crucial role in biological processes such as tissue growth and tumorigenesis. Biomedical research that focuses on understanding the mechanisms of cell motility generates large amounts of multidimensional image data acquired by fully automated optical microscopes. Manual analysis of such data is extremely laborious and therefore, it is necessary to develop reliable automatic methods of image analysis. However, evaluation and assessment of such methods remains a challenging task, since in the case of real data, no ground truth is available to establish simple and robust metrics. Therefore, an important task in development of automatic methods of image analysis is the synthetic generation of realistic images allowing for quantitative assessment based on the ground truth.

We collaborate with the Centre of Biomedical Image Analysis (CBIA) at Masaryk University, Czech Republic on the development of reliable image analysis methods for quantitative characterization of cell motility driven by cellular protrusions at the leading edge of crawling cells. In particular, we develop physics-based models of living cells which are used to generate synthetic time-lapse 3D image series that realistically mimic the motile cells with protrusions (Figure 10). Although modeling of living cells has many specificities, we successfully exploit the modeling algorithms originally designed and developed for the simulation soft tissues. We have already demonstrated that realistic simulation of living cells can be achieved using SOFA and are working toward more complex models and scenarios, involving interactions among the cells and mitosis.

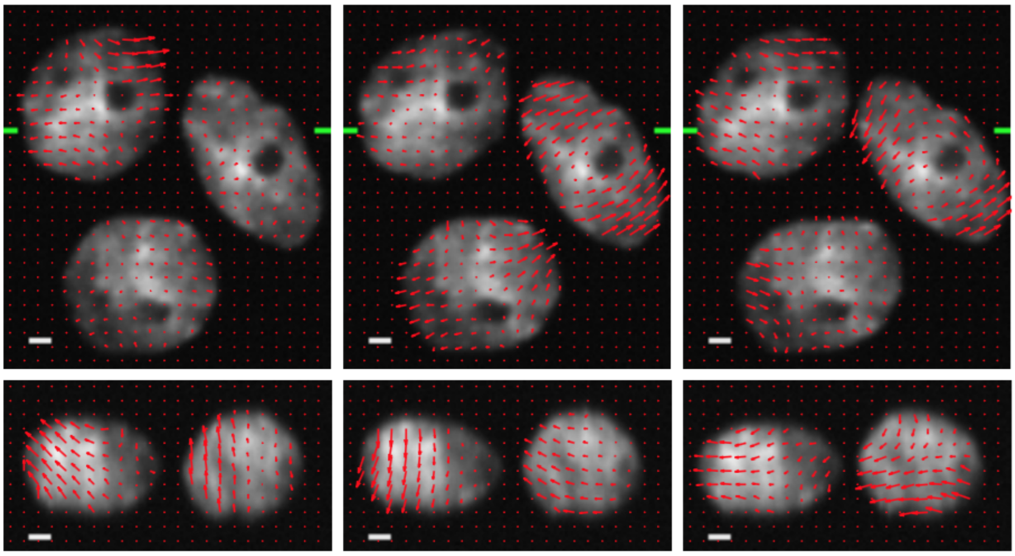

Figure 10. Sample synthetic nuclei generated with our method.

5.6. Training for retina surgery

Participants: Rémi Bessard Duparc, Stéphane Cotin.

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 from accreditation or recertification from surgical societies on the other hand, we are developing a high-fidelity training system for retinal surgery.

This simulator is 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. The simulation system 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 funded through the ANR project RESET). A first version of the training system has been developed and demonstrated in different ophthalmology conferences.

5.7. Robotic control of flexible needle insertion

Participants: Yinoussa Adagolodjo, Hadrien Courtecuisse.

We introduce a new method for automatic robotic needle steering in deformable tissues [13]. It uses an inverse Finite Element (FE) simulation to control an articulated robot interacting with deformable structures. We consider a flexible needle, embedded in the end effector of a 6 arm Mitsubishi RV1A robot, and its insertion into a silicone phantom. Given a trajectory on the rest configuration of the silicone phantom, our method provides in real-time the displacements of the articulated robot which guarantee the permanence of the needle within the predefined path, taking into account any undergoing deformation on both the needle

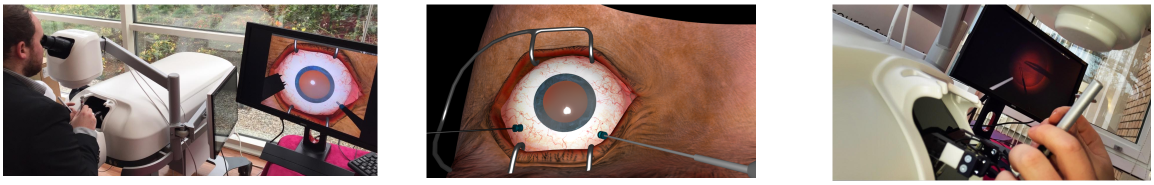

Figure 11. Left: the simulation is performed on a dedicated hardware including a microscope and instruments. Middle: The instruments are inserted in the eye. Right: The epiretinal membrane is removed.

and the trajectory itself. A forward simulation combines i) a kinematic model of the robot, ii) FE models of the needle and phantom gel iii) an interaction model allowing the simulation of friction and puncture force. A Newton-type method is then used to provide the displacement of the robot to minimize the distance between the needle's tip and the desired trajectory. We validate our approach with a simulation in which a virtual robot can successfully perform the insertion while both the needle and the trajectory undergo significant deformations.

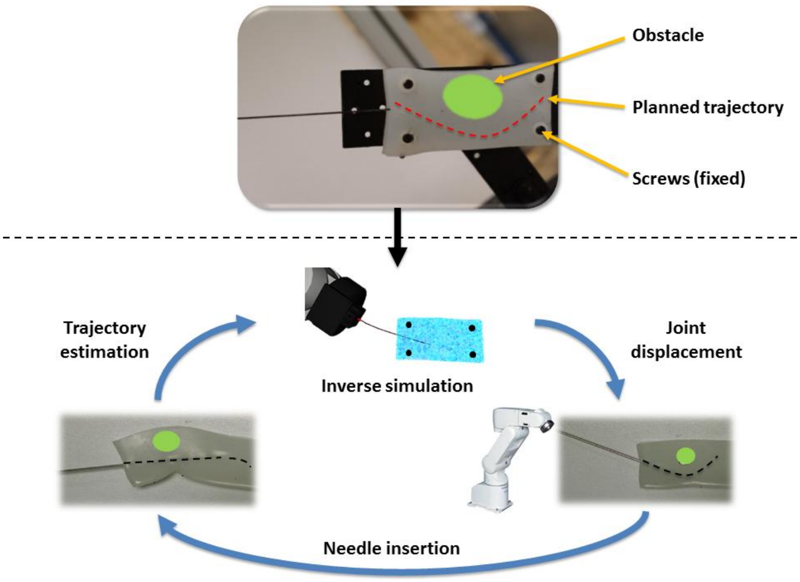

Figure 12. Automatic robotic needle steering in deformable tissues.

5.8. Compensation of brain shift in brain tumor surgery

Participant: Hadrien Courtecuisse.

During brain tumor surgery, planning and guidance are based on pre-operative images which do not account for brain-shift. However, this shift is a major source of error in neuro-navigation systems and affects the accuracy of the procedure. The vascular tree is extracted from pre-operative Magnetic Resonance Angiography and from intra-operative Doppler ultrasound images, which provides sparse information on brain deformations.

The pre-operative images are then updated based on an elastic registration of the blood vessels, driven by a patient-specific biomechanical model. We develop a biomechanical model [17] to extrapolate the deformation to the surrounding soft tissues. Our method has proved to efficiently compensate for brain deformation while being compatible with a surgical process.

5.9. Regional anaesthesia

Participants: Rémi Bessard Duparc, Stéphane Cotin.

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. Our work lead to the following journal article (submitted in Sept 2016) : *Real-time error controlled adaptive mesh refinement: Application to needle insertion simulation*.

This paper presents the first real-time discretization-error-driven adaptive finite element approach for corotational elasticity problems involving strain localization. We propose a hexahedron-based finite element method, combined with a posteriori error estimation driven local h-refinement, for simulating soft tissue deformation. This enables to control the local error and global error level in the mechanical fields (e.g. displacement or gradient) during the simulation. The local error level is used to refine the mesh only where it is needed, while maintaining a coarser mesh elsewhere. We investigate the convergence of the algorithm on academic examples, and demonstrate its practical usability on a percutaneous procedure involving needle insertion in soft tissues.

2016 was the third year of the project 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.

See the RASimAs web site for more details.

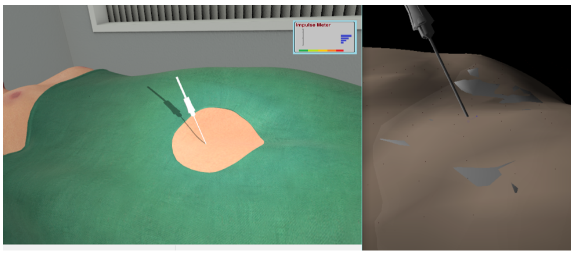

Figure 13. Left: Interface of the RASimAs simulator during femoral nerve block. Right: The RASimas developer team at the General Assembly.

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contracts with Industry

The team is in close collaborations with:

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). 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. We collaborate with InSimo through the RESET ANR project.

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

Altran is a global leader in innovation and high-tech engineering consulting, Altran accompanies supports its clients in the creation and development of their new products and services. At the occasion of Altran internal scientific workshop, several members of the team (Rosalie Plantefève, Bruno Marques Jaime Guevara and Christoph Paulus) presented their work. We collaborate with Altran through the PhD thesis of Rosalie Plantefeve.

Anatoscope is a young start-up company created in 2015 by researchers, engineers and one surgeon. It develops 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. We collaborate with TruPhysics through the RASimAs FP7 project.

7. Partnerships and Cooperations

7.1. Regional Initiatives

7.1.1. Institut Hospitalo-Universitaire de Strasbourg

Our team has been selected to be part of the IHU of Strasbourg. This institute is a very strong innovative project of research dedicated to future surgery of the abdomen. It is dedicated to minimally invasive surgery, 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). The MIMESIS team is an important part of the project. Since September 2011, we develop numerous experimental activities in close collaboration with clinicians.

7.1.2. Other research teams

At the regional level, the MIMESIS team also collaborates with:

Inria Magrit team: we closely collaborate with the Magrit team on the use of augmented reality in surgical procedures, through the PhD thesis of Jaime Garcia Guevara and the postdoctoral position of Nazim Haouchine. This collaboratin leads to many publications [14].

ICube *Automatique Vision et Robotique* (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 *Informatique Géométrique et Graphqiue* (IGG) team: the Mimesis team joined the IGG team and develops collaboration in the domain of dynamic topologies, mainly through the use of the CGoGN framework. CGoGN is a C++ library for the manipulation of meshes. It implements combinatorial maps and their multiresolution extensions and has been used in various high level application like the simulation of crowds of autonomous agents and the simulation of cuts, tears and fractures in the context of surgical simulations.

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 which started in March 2015. We also collaborate with Prof. Patrick Pessaux, a surgeon who helps us in the context of the SOFA-OR project.

7.1.3. ADT: Aide au Développement Technologique

The MIMESIS receives support for the development of the SOFA framework through two ADT:

SofaOR (Jan 2015-Dec 2016): The objective of this ADT was twofold: first, we aimed 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 was 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.

DynMesh (Sep 2015-Aug 2017): The objectives of this ADT was the coupling of SOFA, the physical simulation platform supported by Inria, and CGoGN, the mesh management library developed within the ICube lab at Strasbourg. The goal is to extend 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.

7.2. National Initiatives

7.2.1. ANR

MIMESIS participates to the following ANR project:

RESET: This project started in March 2015 and will end in May 2017. 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).

Coordinator: MIMESIS

Partners: the InSimo company, the AVR team of the ICube lab.

7.2.2. National Collaborations

At the national level, the MIMESIS team collaborates with:

The LML laboratory *(Laboratoire de Mécanique de Lille)*: a French research laboratory (UMR CNRS 8107) part of the Carnot institute ARTS. With more than two hundred researchers, LML focuses on the following research areas: mechanical reliability and Tribology, fluid mechanics, civil engineering and soil mechanics.

The TIMC laboratory *(Techniques de l'Ingénierie Médicale et de la Complexité)* in 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 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,

7.3. European Initiatives

7.3.1. FP7 & H2020 Projects

MIMESIS participates to the following European project:

Program: FP7

Project acronym: **RASimAs**

Project title: Regional Anaesthesia Simulator and Assistant

Duration: Nov 2013 - Nov 2016

Coordinator: Department of Medical Informatics, Uniklinik RWTH Aachen (Germany)

Other partners: we collaborate, among others, with: the University Hospital Aachen, RWTH Aachen, 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.

Abstract: The goal of this project was to increase the application, the effectiveness and the success rates of regional anaesthesia and furthermore the diffusion of the method into a broader clinical use through the development of clinical tools to train new anaesthesiologists and assist them during the operation. The project combine two independent but complementary systems: one system is for training and the other one is for operational guidance. The training system consists in one medical simulator recreating RA operation for the anaesthesiologist in a virtual reality environment. The trainee is able to practise virtually the operation on various patient anatomies. The guidance system consists in assisting anaesthesiologists during the practise of RA by providing enhanced feedback on image interpretation and patient-specific anatomy. These two prototypes have been evaluated through a multi-centre clinical trial in Germany, Belgium and Ireland.

7.4. International Initiatives

The MIMESIS team has collaboration with the following international partners:

- **Team Legato, University of Luxembourg**: since last year we have active collaborations with Prof. Stéphane Bordas on real-time soft tissue cutting simulation. This has already led to a journal article [19] and the co-supervision of a post-doctoral fellow ;
- **Humanoid and Intelligence Systems Lab, Karlsruhe Institute of Technology**: we started a collaboration with Stefanie Speidel and Stefan Suwelack on the topics of real-time soft tissue modeling and laparoscopic augmented reality.
- **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).
- **Faculty of Informatics, Masaryk University, Czech Republic**: We began collaborations with Professor Ludek Matyska on biomedical simulations. The PhD thesis of Lukas Rucka on the Validation and verification of soft tissue models; takes place in this context.

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific Events Selection

8.1.1.1. Chair of Conference Program Committees

- Igor Peterlik was chair in the Workshop on Mathematical and Engineering Methods in Computer Science, October 21 — 23, Telc, Czech Republic
- Nazim Haouchine was a co-chair of the Medical Robotics session at IROS 2016, the International Conference on Intelligent Robots and Systems

8.1.1.2. Reviewer

- Hadrien Courtecuisse made reviews for the IEEE Haptics Symposium and the conference Medical and Biological Engineering and Computing
- Nazim Haouchine made reviews for the International Symposium on Biomedical Imaging

8.1.2. Journal

8.1.2.1. Reviewer - Reviewing Activities

- David Cazier is reviewer for the Computer-Aided Design Journal and for the International Journal of Virtual Reality
- Igor Peterlik is reviewer for the following journals: IEEE Transaction on Haptics, IEEE Transaction on Industrial Electronics, IEEE Transaction on Visualization and Computer Graphics and Computer and Graphics
- Hadrien Courtecuisse is reviewer for the journal Transactions on Haptics and Visual Computer
- Nazim Haouchine made reviews for the International Journal of Computer Assisted Radiology and Surgery

8.1.3. Invited Talks

- Stéphane Cotin gave an invited talk at the 14th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering (Tel Aviv, Israel, 2016)

8.1.4. Scientific Expertise

- Igor Peterlik made scientific expertises at Masaryk University for teaching, supervision of master and Ph.D. students and scientific consultations. Active participation at project funded by Grand Agency of the Czech Republic: *Development of Reliable Methods for Automated Quantitative Characterization of Cell Motility in Fluorescence Microscopy*.

8.1.5. Research Administration

- GTAS : David Cazier heads (with Marc Parenthoen) the national Workgroup on Animation and Simulation of the GDR IG-RV since 2014

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

- Master: Stéphane Cotin, *Medical Imaging (4h)*, M2, Arts et Métiers ParisTech - Paris, France
- Master: Stéphane Cotin, *Medical Imaging (4h)*, M2, Master of Surgical Sciences - Paris, France
- Master: Igor Peterlik, *Modélisation des Systèmes Vivants (10h)*, M2, Master TIC-Santé, Télécom Physique Strasbourg
- Master: Hadrien Courtecuisse, *Real time simulation (30h)*, M2, Master TIC-Santé, Télécom Physique Strasbourg
- Master: Hadrien Courtecuisse, *Real time simulation (10h)*, M1, Master IRMC, Télécom Physique Strasbourg
- Licence: David Cazier, *Web technologies and programming (96h)*, Licence, Université de Strasbourg, France

8.2.2. Supervision

- PhD : Rosalie Plantefeve, *Augmented reality and numerical simulations for resection of hepatic tumors*, Université de Lille, defended on 08/06/2016, supervised by Stéphane Cotin
- PhD in progress: Christoph Paulus, *Modélisation et simulation temps-réel pour la prise en compte des changements topologiques dans les tissus mous*, 01/01/2014, supervised by David Cazier, Stéphane Cotin
- PhD in progress: Jaime Garcia Guevara, *Augmented ultrasound imaging for hepatic surgery*, 01/09/2015, supervised by Stéphane Cotin, Marie-Odile Berger
- PhD in progress: Raffaella Trivisonne, *Computer-aided vascular interventions*, 01/09/2015, Stéphane Cotin, Erwan Kerrien
- PhD in progress: Yinoussa Adagolodjo, *Coupling between robotics and medical simulation for automated procedures*, 01/02/2015, supervised by Hadrien Courtecuisse
- PhD in progress: Fanny Morin, *Non linear simulation for intraoperative guidance for neurosurgery*, 01/10/2014, supervised by Yohan Payan, Matthieu Chabanas, Hadrien Courtecuisse (collaboration with the TIMC laboratory, Grenoble)
- PhD in progress: Lukas Rucka, *Validation and verification of soft tissue models*, 2016 - 2019, supervised by Igor Peterlik and Professor Ludek Matyska in the scope of an international collaboration with Faculty of Informatics, Masaryk University, Czech Republic.
- Master thesis in progress: Petra Ondrejkova, *Contact modeling for forward and inverse simulations of deformable objects in Matlab*, 01/09/2016 - 31/07/2017 , supervised by Igor Peterlik and Prof. Ludek Matyska in the scope of an international collaboration with Faculty of Informatics, Masaryk University, Czech Republic.

8.2.3. Juries

- HdR defense: Benoit Crespin, *Modélisation d'objets complexes, simulation de fluides et interactions*, 14/12/2016, Université de Limoges, David Cazier (reviewer)
- PhD defense: Armelle Bauer, *Modélisation anatomique utilisateur spécifique et animation temps réel : Application a` l'apprentissage de l'anatomie*, 11/11/2016, Université Grenoble, Stéphane Cotin (reviewer)
- PhD defense: Yuen Law, *Real-Time Simulation of B-Mode Ultrasound Images for Medical Training*, 23/11/2016, RWTH Aachen, Germany, Stéphane Cotin (reviewer)
- PhD defense: Lucas Royer, *Real-time Tracking of Deformable Targets in 3D Ultrasound Sequences*, 12/12/2016, INSA Rennes, France, Stéphane Cotin (reviewer)

8.3. Popularization

Stéphane cotin gave invited talks at:

- the Fist European workshop on Nanomedicine, Modeling, Virtual Reality and Robotics applied to surgery (Strasbourg, 2016)
- the Business Engineering and Surgical Technologies symposium (Strasbourg, 2016)
- the OpenYourMind seminar (Paris, 2016)
- IHU Scientific meeting on registration and augmented reality (Strasbourg)

Members of the MIMESIS team contributed to the following events:

- presentation of our research activities during several IHU fellow meetings
- demonstration of our prototype of retina surgery training system during the national congress of ophthalmology (May 2016, Paris)
- demonstration of our prototype of retina surgery training system during the DMLA meeting (September 2016, Paris)
- demonstration of our prototype of retina surgery training system during the regional ophthalmology meeting (November 2016, Strasbourg)

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Major publications by the team in recent years

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Publications of the year

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[8] R. PLANTEFÈVE. *Augmented Reality and Numerical Simulations for Hepatic Tumors Resection*, Université Lille 1 Sciences et Technologies, June 2016, https://hal.inria.fr/tel-01338385

Articles in International Peer-Reviewed Journals

[9] E. KERRIEN, A. YUREIDINI, J. DEQUIDT, C. DURIEZ, R. ANXIONNAT, S. COTIN. *Blood vessel modeling for interactive simulation of interventional neuroradiology procedures*, in "Medical Image Analysis", January 2017, vol. 35, pp. 685 - 698 [*DOI :* 10.1016/J.MEDIA.2016.10.003], https://hal.inria.fr/hal-01390923

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