S3PM

# Project S3PM
# « Synthesis and Simulation of Surgical Process Models »

# 1 Abstract

Non organic simulators for surgical professionals have the potential to improve training and performance of the whole surgical team. To ensure pedagogical relevance, S3PM proposed an innovative approach that model and simulate surgical scenarios with high variability and complexity in a collaborative virtual reality environment. We demonstrated the feasibility of the approach by implementing a scenario for neurosurgical scrub nurses. We demonstrated the acceptability of the developed system in a population of non professionals and scrub nurses. The proposed approaches have the potential to be used in any generic procedural context with high complexity and variability. In addition, the S3PM project allowed to create a multi disciplinary consortium including partners from medical data science and ontology, surgery, process mining, virtual reality, with additional partners on behavioral psychology and nurse education that join the consortium in the SunSET project. This rare consortium has the ambition to create an unique working group around these technologies and challenges.

# 2 Context and motivations

There are about 50 millions of surgical procedures per year in USA (250 millions worldwide, 6 and 8 millions in France). Several reports estimated that between 250.00 and 300.00 preventable serious adverse events appeared every year with mortality consequences in USA (around 0.5%). It makes medical errors as the third cause of death in the USA majority is related to non-technical skills. To ensure patient safety and reduce serious adverse events, several strategies have to be implemented. Better surgical training and evaluation with medical simulators is one of them. Other drivers are related to the development and use of simulators for training and evaluating surgical professionals. The first time a professional operates on a patient should be delayed as late as possible in the learning curve, whereas nowadays the learning curve is acquired during clinical practice. There is an increase of quantity and expected quality of surgical procedures from the society. There are more trainees to train and less available experts with regularly new available surgical techniques to learn (laparoscopy, robotics, …). There is an economic expectation for accelerating the learning curve. At last but not least, there is a tendency of developing multi purpose operating rooms where the surgical staff has to be trained for different surgical contexts and procedures.

Despite this strong need for more initial and continuous training and except in very specific surgical contexts, few training systems are available and deployed. In medical procedures, there is a trend for incorporating more and more training systems in the curriculum for general medicine or obstetrics, for instance. Main limitations of current training systems include the high cost and time required to produce new cases and procedures, the lack of realistic surgical scenarios as well as the lack of systems dedicated to procedural knowledge. The latter was identified as an important part of the surgical skills.

The S3PM project proposed, developed and validated a new approach for addressing the need of surgical simulators for training procedural skills. It relies on 3 technologies: 1) surgical process modeling, 2) workflow mining, and 3) collaborative virtual reality. This addressed 3 main limitations: 1) the development of realistic scenarios from formal observations and learning, 2)

the development of variable and complex scenarios from synthesis of various observations, and 3) the development of software facilitating interactions with the virtual environment. Two scenarios were implemented for neurosurgical scrub nurses: a simple scenario including the first 6 actions within a craniotomy on which concepts were tested, and a more complex realistic scenario of a surgical table set-up on which experiments were performed.

# 3 Main contributions

The project contributed on four aspects. The first aspect concerned the study and design of an ontology for describing and representing the procedural dimension of surgery. The second aspect concerned the study of methods for computing and representing the procedural variability from a population of individual descriptions of procedures. The third task aspect concerned the study and adaptation of virtual reality based simulation engines for the execution of these models representing the variability. Finally, the fourth aspect concerned the design of a prototype of a training system and the study of its feasibility for a specific application.

## 3.1 Ontologies for describing and representing the procedural dimension of surgery

During the S3PM project, we studied and designed an ontology for describing and representing the procedural dimension of surgery. We decided to decompose this ontology into two parts: 1) a generic one (called OntoSPM), gathering vocabulary that may apply to almost any domain of surgery (e.g. to denote actions, surgical instruments, roles, anatomical structures), and 2) a specific one (called OntoS3PM), addressing the specific needs of the scenarios considered in the S3PM project for the training of neurosurgical scrub nurses (i.e. focusing on the craniotomy phase in tumor surgery and on the preparation of the scrub nurse's table). OntoS3PM was used to annotate a set of real procedures from video records. As for OntoSPM, we realized that its value will arise from a wide scale adoption by the Surgical Data Science community, so we decided to launch an international initiative for extending and disseminating this ontology worldwide. A two-day workshop was organized in Rennes in April 2016 gathering about 50 people from Europe. This workshop led to an international collaboration called "OntoSPM Collaborative Action"[1]. The people involved meet every month for a technical meeting and every two-month for a strategic meeting. This collaborative action currently includes 15 partners involved in the continuous development of the ontology. As an extension of this initiative, we submitted in December 2016 a COST ACTION proposal named "Sharing Data and Knowledge for Surgical Data Science", consisting of a network of 47 researchers from 30 institutions located in 14 (mostly) European countries. The proposal was rejected and resubmitted in 2017 under the name of SurgiData, with significant extension toward clinicians and manufacturers (74 researchers from 19 countries).

[1] https://ontospm.univ-rennes1.fr/doku.php?id=start

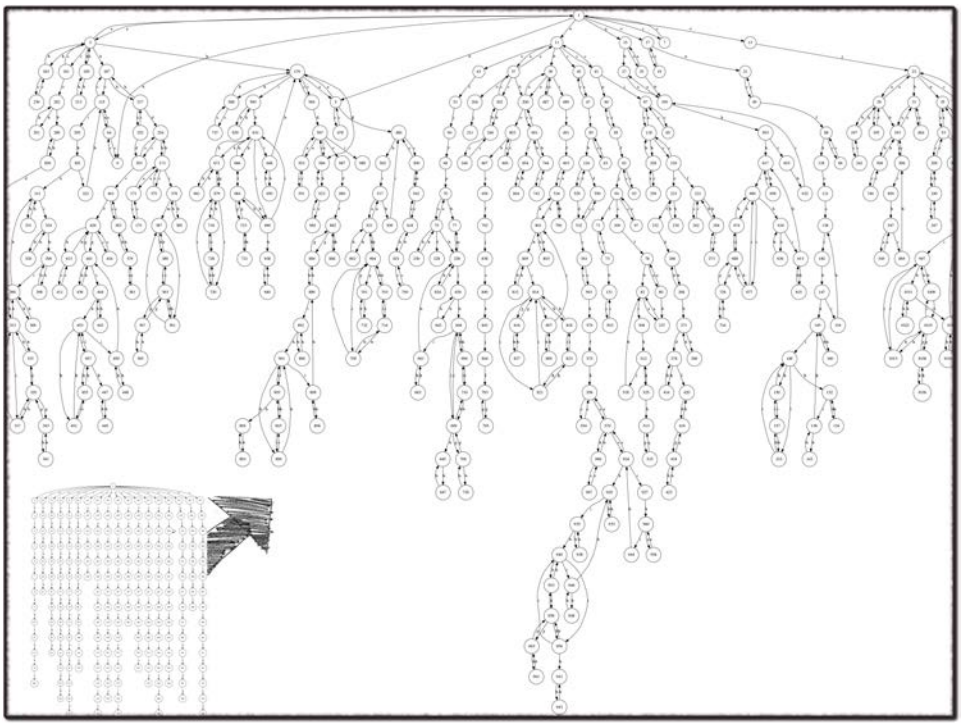

OntoS3PM: parts of the ontology

## 3.2 Test and Flip: Synthesis of surgical process models

During the S3PM project, we studied and designed an approach for synthesizing surgical process models from a set of instances of surgical procedures. The method consists in the synthesis of a Test and Flip Petri net[2], which language is, by construction, the least language of a Test and Flip net, containing the set of behavior contained in the instances. The algorithm is based on the theory of Regions[3] and reduces to linear algebraic computations in the Boolean ring. It has a low algorithmic complexity and scales up to long procedure recordings. The synthesized net captures the causality and conflict relations between the actions occurring in the procedure recordings. A key property of the algorithm, is that it is capable of generalizing sequences of actions, that are likely to be meaningful, but have not been observed in the recordings. Contrarily to statistical machine learning techniques, the method is capable of synthesizing meaningful models from relatively small sets of examples. A validation of the synthesized model, by a surgeon expert in the type of procedure, is nevertheless required.

A software tool, Demodocos, implementing this algorithm has been released under a CeCILL-C (LGPL-like) open-source license. It takes as input surgical procedure recordings produced by the SurgeTrack software developed at IRT B-Com and instantiating the OntoS3PM ontology. The tool can generate procedure models in #SEVEN syntax, that can be simulated in the virtual reality environment described below. Thanks to this feature, the Demodocos software enables a seamless workflow from individual procedure recordings down to the simulation of the synthesized procedural model in a virtual reality environment.

[2] https://hal.inria.fr/hal-00872284
[3] https://hal.inria.fr/hal-01237142



Example of a synthesis of surgical process models

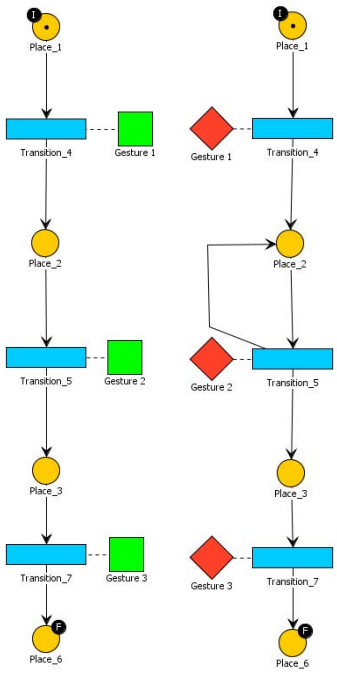
### 3.3 Seven: a library for the simulation of process models

During the S3PM project, we studied and designed an approach for simulation of complex procedural scenarios, named #SEVEN. #SEVEN (Sensor Effector Based Scenarios Model for Driving Collaborative Virtual Environments) is a sensor effector based scenario engine that enables the execution of complex scenarios for driving Virtual Reality applications. #SEVEN's scenarios are based on an enhanced Petri net model which is able to describe and solve intricate event sequences. #SEVEN comes with an editor for creating, editing and remotely controlling and running scenarios. #SEVEN is implemented in C# and can be used as a stand-alone application or as a library. An integration to the Unity3D engine, compatible with MiddleVR, has been developed. #SEVEN is strongly connected to #FIVE (Framework for Interactive Virtual Environments) in order to provide a complete VR oriented framework on top on Unity3D[4] (a professional game development platform). #FIVE was not developed in the context of S3PM but due to its functionalities we intensively used it. #FIVE is a framework for the development of interactive and collaborative virtual environments and provides a toolkit that simplifies the declaration of possible actions and behaviours of objects in a VE. These modules can be used in a vast range of domains using virtual reality applications and requiring interactive environments and collaboration, such as in training for example. During the S3PM project #SEVEN and #FIVE where freely tested by Orange Labs and IRT b<>com (2016-2017).

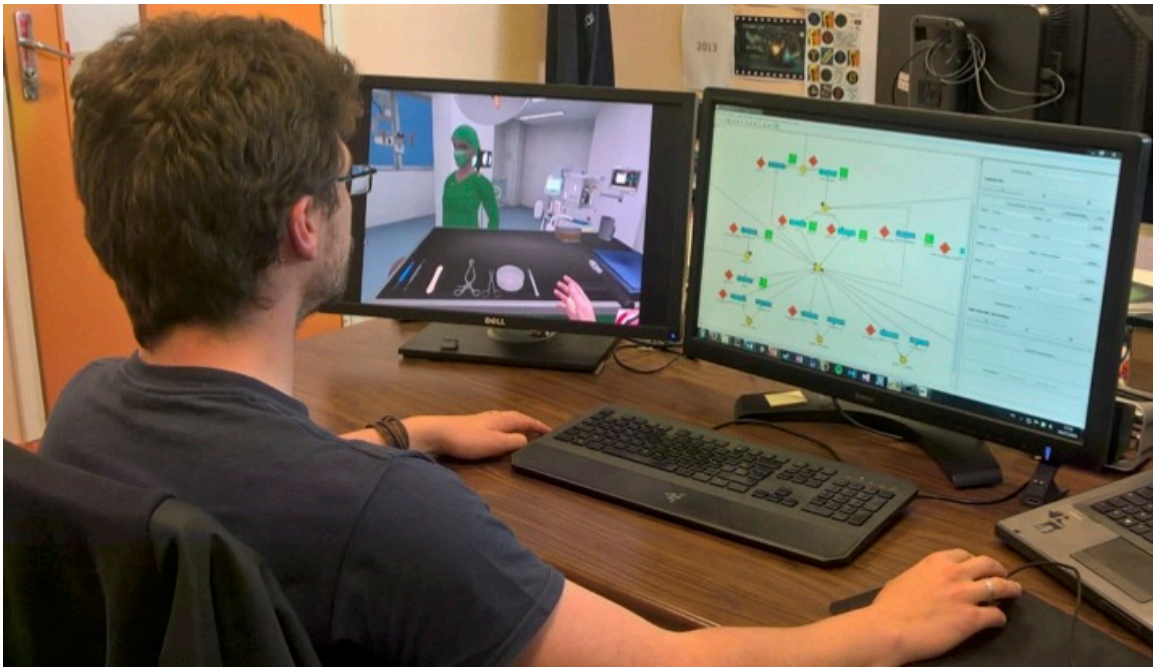
Currently, a valorization operation is organized within the framework of the SATT-Ouest-Valorisation in order to develop the line of tools #SEVEN and #FIVE. In this context, we obtained grants for 3 software engineers over a period of 18 months each. Their objectives are:

[4] https://unity3d.com/

- to make the tools more operational and more usable
- to develop a new version for #SEVEN Editor
- and to offer both a complete documentation and tutorials on many application domains.

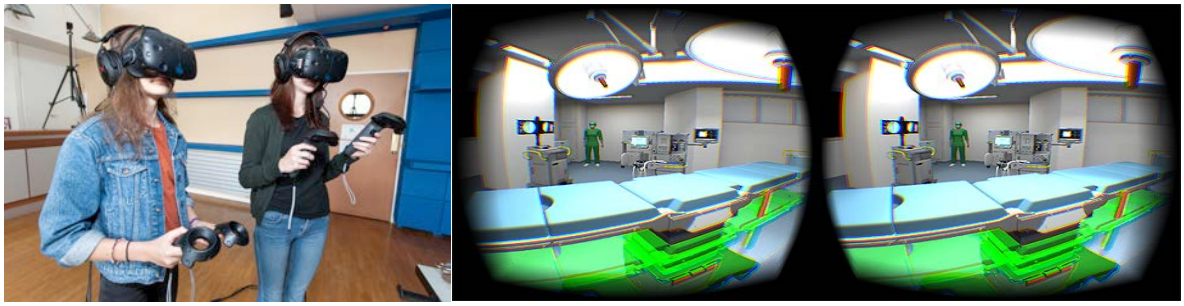



Example of a #SEVEN workflow



Development of #SEVEN scenario (right screen) and 3D execution (left screen)

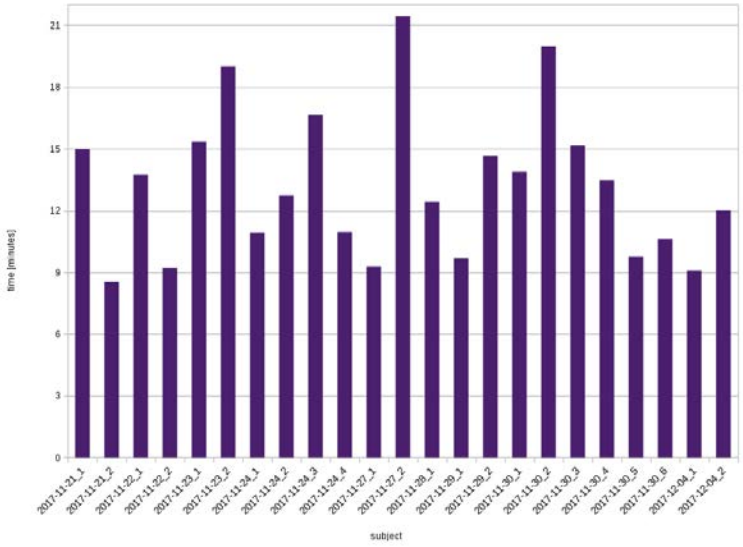
3D environment of the surgery room



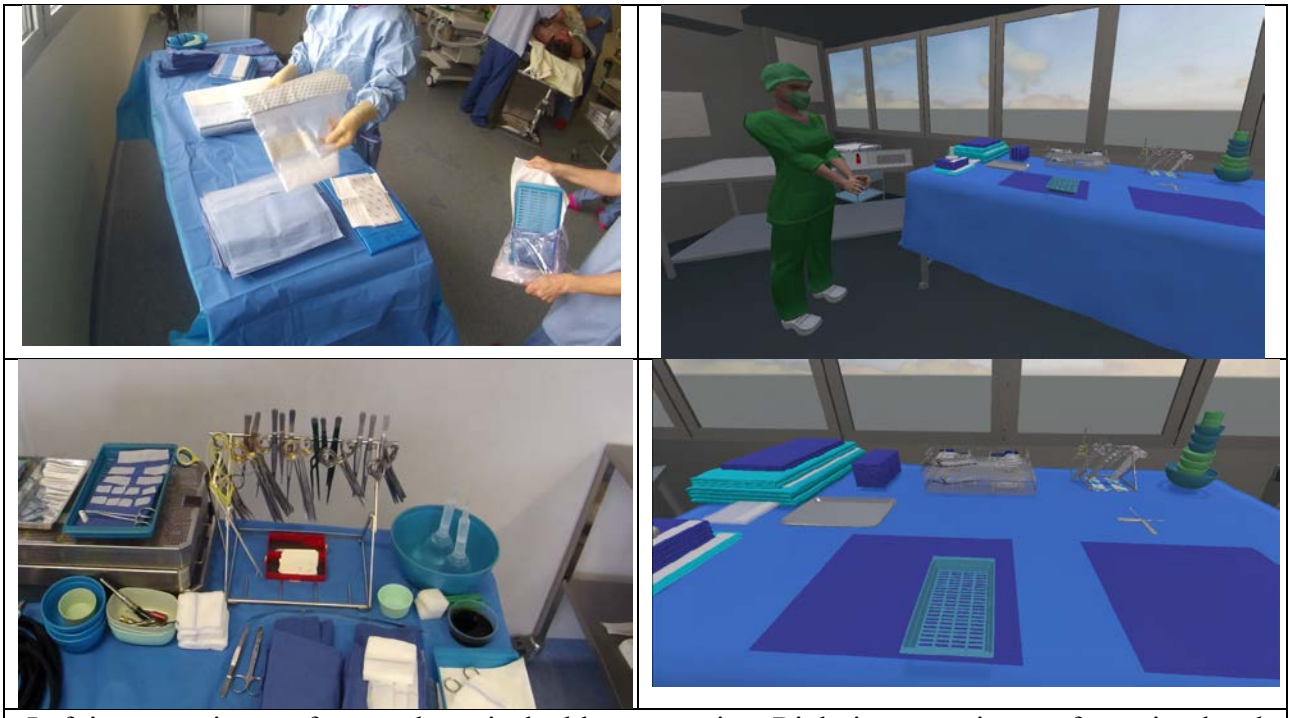
HTC Vive experiment setup

### 3.4 Vitrail: Virtual training simulator for Neurosurgical Scrub Nurse

During the S3PM project, we implemented the methods within two exemplary scenarios and systems. The first was developed early in the project to present the studied concepts. It concerned a simple scenario including the first 6 actions within a craniotomy. The trainee (or user) has to act as a neurosurgical scrub nurse in the course of a neurosurgical procedure. The user has to give to the virtual surgeon and the virtual assistant the required surgical instruments in a strict order.
The second developed system consists in a VR based simulation system for training scrub nurses in a neurosurgical table preparation. It consists in collaborating with a circulating scrub nurse to prepare the surgical instruments needed for the surgical procedure. This preparation consists in organizing boxes, each box corresponding to a dedicated surgical phase. This is a perfect example of procedural knowledge to acquire during surgical scrub nurse training. The implemented scenario replicates about 6 minutes of a global procedure that usually takes between 15 and 20 minutes. The scenario was build according the S3PM methodology including video observations of real cases. The simulated scenario involved about 80 different surgical instruments and about 24 different interactions with the virtual world. We designed and implemented user experiments to study the acceptability of the system. The acceptability was studied along three axis: acceptability of the VR immersion in a 15 minutes experiment, acceptability of the interaction with the virtual world, and acceptability of the professional scenario. In order to train the users to the VR technology, we implemented a scenario for test which consists in a Russian doll task. A pre test session involved 23 non professionals to ensure technical validity between November 20$^{th}$ to December 6$^{th}$ 2017. The experiments with scrub nurses are planned for January 2018.




Time spent by 23 users in executing the whole table preparation scenario



Left images: pictures from real surgical table preparation, Right images: pictures from simulated corresponding images in the Vitrail S3PM simulator

# 4 Participants

## 4.1 Recruited peoples

| Name | Starting time | Ending time | Role in S3PM |
|---|---|---|---|
| Cédric Pénet | January 2013 | December 2014 | Post-doctoral position: Implementation and test of Test & Flip approach for synthesis of surgical process models |
| Guillaume Claude | September 2013 | Juin 2016 | PhD position: Development of Seven framework and Vitrail system |
| Javier Rojas Balderama | September 2015 | May 2017 | Post-doctoral position: Development of OntoSPM ontology and associated software, data acquisition and annotation, development of Vitral system, lead of technical development |

## 4.2 Permanent peoples

| Name | Team | Position |
|---|---|---|
| Pierre Jannin | MediCIS/LTSI | DR2 Inserm (Team Leader) |
| Bernard Gibaud | MediCIS/LTSI | CR1 Inserm |
| Xavier Morandi | MediCIS/LTSI | Professor, MD, PhD, Head of the Neurosurgical Department of the University Hospital, Rennes |
| Laurent Riffaud | MediCIS/LTSI | Associate researcher, MD, PhD, Neurosurgical Department of the University Hospital, Rennes |
| Emmanuelle Mondin | CHU | Cadre hospitalier |
| Bénédicte Nogues | CHU | Neurosurgical scrub nurse |
| Pierre-Louis Henaux | MediCIS/LTSI | PhD student, MD, Neurosurgical Department of the University Hospital, Rennes |
| Bruno Arnaldi | Hybrid, IRISA/Inria | Professor, INSA Rennes |
| Valérie Gouranton | Hybrid, IRISA/Inria | Associate professor, INSA Rennes |
| Benoit Caillaud | S4, IRISA/Inria | DR1 Inria (Team leader) |
| Philippe Darondeau | S4, IRISA/Inria | CR1 Inria |

# 5 Results

## 5.1 Qualitative own assessment

We decided to pursue the S3PM project with an emphasis of non technic skills and the development of corresponding new scenarios. The *SunSet* project is based on the same operational consortium plus researchers on Humanities (CRPCC University of Rennes 2). It aims at developing an innovative training software suite based on immersive and collaborative virtual reality technology for training and evaluating non-technical skills. I will be implemented and evaluated in the context of training neurosurgical scrub nurse.

## 5.2 Scientific achievements

### 5.2.1 PhDs

- PhD defense from Guillaume Claude

### 5.2.2 Scientific Publications

- Gibaud B., Penet C., Jannin P. (2014) OntoSPM: a Core Ontology of Surgical Procedure Models, Surgetica
- Caillaud B. (2013) Surgical Process Mining with Test and Flip Net Synthesis. In Application of Region Theory (ART)
- Claude G., Gouranton V., Berthelot R. B., Arnaldi B. (2014). #seven, a sensor effector based scenarios model for driving collaborative virtual environment. In ICAT-EGVE
- Claude G., Gouranton V., Caillaud B., Gibaud B., Jannin P., Arnaldi B. (2016). S3PM: Synthesis and Simulation of Surgical Process Models. In MMVR 2016, Los Angeles, USA
- Claude G., Gouranton V., Caillaud B., Gibaud B., Jannin P., Arnaldi B. (2016). From Observations to Collaborative Simulation: Application to Surgical Training. ICAT-EGVE, Little Rock, USA
- Gibaud B. Semantic models and ontologies in Surgical Data Science. Workshop on Surgical Data Science, June 20, 2016, Heidelberg (Germany).
- G Claude, V Gouranton, B Arnaldi, Versatile Scenario Guidance for Collaborative Virtual Environments, GRAPP 2015, Berlin, Germany
- G Claude, V Gouranton, B Arnaldi, Roles in collaborative virtual environments for training ICAT-EGVE 2015, Kyoto, Japan
- Guillaume Claude, Valérie Gouranton, Rozenn Bouville Berthelot, Bruno Arnaldi, #SEVEN, a Sensor Effector Based Scenarios Model for Driving Collaborative Virtual Environment, ICAT-EGVE, International Conference on Artificial Reality and Telexistence, Eurographics Symposium on Virtual Environments, Dec 2014, Bremen, Germany. pp.1-4, 2014

### 5.2.3 Publications Grand Public

- Sciences et Vie 2017
- L'Express Avril 2017
- Le courrier du CHU de Rennes Juin 2015

## 5.3 Valorisation

- Patent submitted «Système de Simulation basé sur un apprentissage, dispositifs, méthodes et programmes correspondants» R25634FR
- APP software protection
  - Test&Flip software to be submitted
  - #SEVEN: IDDN FR 001 340035 000 SP 2015 000 10000, August 2015

In the course of the S3PM project, we had a lot of contacts with industry to present our solutions, including the following:

- Society **TIETRONIX** Inc 1331 Gemini, ste 300 Houston, Tx 77058: Several visits were organized the CTO of the society visited MediCIS lab in April 2015.
- Society **Haption** Laval France Several meetings were organized with the CTO and CEO of the society in November 2015.
- Society **SAP** France Several meetings were organized with the CTO and CEO of the society in Mars 2017.
- **Vivalto** Santé CHU St Grégoire France Contacts in May 2017.
- Society **MediPIX** Rennes France Several meetings were organized with the CEO of the society in September 2017.
- Society **Orange Labs** Rennes: #SEVEN and #FIVE where tested during 2016 and 2017
- **IRT b<>com** Rennes: #SEVEN and #FIVE where tested during 2016 and 2017

## 5.4 Presentations and demos

### 5.4.1 Institutional demos

- University Hospital of Rennes: CEO (Mme Anatole Touzet), R&D
- Medical University Dean (Pr. Bellissant)
- MMVR Conference Los Angeles (USA)
- Demonstration Dassault System 13/11/2014
- Demonstration General Assembly Visionair (European Project) 2/12/2014
- Demonstration Clarté 5/12/2014
- Demonstration B-Com 12/12/2014
- TECHNOFERENCE#12 Réalité virtuelle, Réalité augmentée - DEMOS - 5 février 2015
- Ecole Architecture Rennes 13/3/2015
- Booth AFRV, conference IEEE VR 23-27/3/2015 – Arles
- Visit of Head of INS2I-CNRS 9/4/2015
- Visit of Head of CNRS Bretagne Pays de Loire 29/5/2015
- Visit of Agences Régionales de Santé 6/7/2015
- Visite IDELE (Institut de l'Elevage) 15/10/2015
- Haut Conseil de l'évaluation de la recherche et de l'enseignement supérieur (HCERES) 19/1/2016
- Visit of Technicolor 3/2/2016
- Forum Eurocities 29/4/2016
- Visit of Renault 4/7/2016
- Visit TransInnov Bretagne Développement Innovation / project INTERREG INKREASE 20/9/2016
- Head of CHU Rennes 26/9/2016

### 5.4.2 Public demos

- Festival “Les Utopiales” Nantes
- Festival TedX Rennes May 2017

## 5.5 New collaborations

- Kyushu University, Fukuoka, Japan (Pr. Hashizume, General Surgeon): Travel grants, several visits at both sides, starting collaboration project
- University Hospital Angers (Pr. Granry, Anesthesiologist, President of the French Society for Simulation in Health Care): Meetings, one research project submitted