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Activity Report 2013

# Project-Team HYBRID

## 3D interaction with virtual environments using body and mind

RESEARCH CENTER
**Rennes - Bretagne-Atlantique**

THEME
**Interaction and visualization**

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## Project-Team HYBRID

**Keywords:** Virtual Reality, Interaction, Simulation, Brain Computer Interface, Collaborative Work, User Interface

*Creation of the Project-Team:* 2013 July 01.

# 1. Members

**Research Scientists**
Anatole Lécuyer [Team leader, Inria, Senior Researcher, HdR]
Ferran Argelaguet Sanz [Inria, Starting Research Position, from Oct 2013]

**Faculty Members**
Bruno Arnaldi [INSA Rennes, Professor, HdR]
Thierry Duval [Univ. Rennes I, Associate Professor, HdR]
Valérie Gouranton [INSA Rennes, Associate Professor]
Maud Marchal [INSA Rennes, Associate Professor]
Thomas Lopez [INSA Rennes, ATER, till Aug 2013]

**Engineers**
Thomas Boggini [INSA Rennes, from Sep 2013]
Rozenn Bouville Berthelot [INSA Rennes, from Feb 2013]
Rémi Félix [Inria, IJD, till Oct 2013]
Jussi Lindgren [Inria]
Jozef Legény [Inria, till Sep 2013]
Thomas Lopez [INSA Rennes, from Sep 2013]
Florian Nouviale [INSA Rennes]
Quentin Petit [INSA Rennes, from Sep 2013]

**PhD Students**
Merwan Achibet [Inria]
Jérôme Ardouin [ESIEA]
Guillaume Claude [INSA Rennes, from Sep 2013]
Fabien Danieau [Technicolor, CIFRE]
Andeol Evain [Univ. Rennes I, from Sep 2013]
Pierre Gaucher [Orangle Labs, CIFRE, till Mar 2013]
François Lehericey [INSA Rennes, from Oct 2013]
Jonathan Mercier-Ganady [Inria]
Thi Thuong Huyen Nguyen [Inria, CORDI-S]
Anthony Talvas [INSA Rennes]

**Post-Doctoral Fellow**
Ferran Argelaguet Sanz [Inria, till Sep 2013]

**Visiting Scientists**
Takuya Sato [Tohoku University, from Oct 2013 till Dec 2013]
Francesco Grani [Aalborg University, Jul 2013]

**Administrative Assistant**
Nathalie Denis [Univ. Rennes 1, in common with EPI Mimetic]

# 2. Overall Objectives

## 2.1. Introduction

Our research project belongs to the scientific field of Virtual Reality (VR) and 3D interaction with virtual environments. VR systems can be used in numerous applications such as for industry (virtual prototyping, assembly or maintenance operations, data visualization), entertainment (video games, theme parks), arts and design (interactive sketching or sculpture, CAD, architectural mock-ups), education and science (physical simulations, virtual classrooms), or medicine (surgical training, rehabilitation systems). A major change that we foresee in the next decade concerning the field of Virtual Reality relates to the emergence of new paradigms of interaction (input/output) with Virtual Environments (VE).

As for today, the most common way to interact with 3D content still remains by measuring user's motor activity, i.e., his/her gestures and physical motions when manipulating different kinds of input device. However, a recent trend consists in soliciting more movements and more physical engagement of the body of the user. We can notably stress the emergence of bimanual interaction, natural walking interfaces, and whole-body involvement. These new interaction schemes bring a new level of complexity in terms of generic physical simulation of potential interactions between the virtual body and the virtual surrounding, and a challenging "trade-off" between performance and realism. Moreover, research is also needed to characterize the influence of these new sensory cues on the resulting feelings of "presence" and immersion of the user.

Besides, a novel kind of user input has recently appeared in the field of virtual reality: the user's mental activity, which can be measured by means of a "Brain-Computer Interface" (BCI). Brain-Computer Interfaces are communication systems which measure user's electrical cerebral activity and translate it, in real-time, into an exploitable command. BCIs introduce a new way of interacting "by thought" with virtual environments. However, current BCI can only extract a small amount of mental states and hence a small number of mental commands. Thus, research is still needed here to extend the capacities of BCI, and to better exploit the few available mental states in virtual environments.

*Our first motivation consists thus in designing novel "body-based" and "mind-based" controls of virtual environments and reaching, in both cases, more immersive and more efficient 3D interaction.*

Furthermore, in current VR systems, motor activities and mental activities are always considered separately and exclusively. This reminds the well-known "body-mind dualism" which is at the heart of historical philosophical debates. In this context, our objective is to introduce novel "hybrid" interaction schemes in virtual reality, by considering motor and mental activities jointly, i.e., in a harmonious, complementary, and optimized way. Thus, we intend to explore novel paradigms of 3D interaction mixing body and mind inputs. Moreover, our approach becomes even more challenging when considering and connecting multiple users which implies multiple bodies and multiple brains collaborating and interacting in virtual reality.

*Our second motivation consists thus in introducing a "hybrid approach" which will mix mental and motor activities of one or multiple users in virtual reality.*

## 2.2. Highlights of the Year

- Anatole Lécuyer was awarded the Inria-Académie des Sciences (French Academy of Sciences) "Young Researcher" Prize 2013.
- Paper  from Anthony Talvas, Maud Marchal and Anatole Lécuyer received the "Best Technote Award" at IEEE Symposium on 3D User Interfaces 2013 (IEEE 3DUI'13).
- Paper  from Ferran Argelaguet, David Gómez Jáuregui, Maud Marchal and Anatole Lécuyer was selected as one of the best papers at ACM Symposium on Applied Perception 2013 (ACM SAP'13).
- Paper  from Charles Pontonnier, Thierry Duval and Georges Dumont was selected as one of the best papers at IEEE Conference on Cognitive Infocommunication 2013 (IEEE CogIncoCom'2013).

- Two projects in which Hybrid is involved were awarded at the trophies "Loading the Future 2013" organized by French Competitivity Cluster "Images et Réseaux": ACOUSTIC (Grand Prize) (section 8.2.4) and W3D (SME Prize) (section 8.1.2).
- Project OpenViBE2 (section 8.2.5) coordinated by Hybrid has received the "Projet Phare" label by French ANR (National Research Agency). It successfully ended in January 2013 year with a press release and a press conference which generated a massive media coverage.

BEST PAPERS AWARDS :

[43] **The God-Finger Method for Improving 3D Interaction with Virtual Objects through Simulation of Contact Area in IEEE Symposium on 3D User Interfaces**. A. TALVAS, M. MARCHAL, A. LÉCUYER.

[14] **Elastic Images: Perceiving Local Elasticity of Images Through a Novel Pseudo-Haptic Deformation Effect in ACM Transactions on Applied Perception**. F. ARGELAGUET SANZ, D. A. GÓMEZ JÁUREGUI, M. MARCHAL, A. LÉCUYER.

[41] **Sharing and bridging information in a collaborative virtual environment : application to ergonomics in IEEE international conference on cognitive infocommunication**. C. PONTONNIER, T. DUVAL, G. DUMONT.

# 3. Research Program

## 3.1. Research Program

The scientific objective of Hybrid team is to improve 3D interaction of one or multiple users with virtual environments, by making full use of physical engagement of the body, and by incorporating the mental states by means of brain-computer interfaces. We intend to improve each component of this framework individually, but we also want to improve the subsequent combinations of these components.

The "hybrid" 3D interaction loop between one or multiple users and a virtual environment is depicted on Figure 1. Different kinds of 3D interaction situations are distinguished (red arrows, bottom): 1) body-based interaction, 2) mind-based interaction, 3) hybrid and/or 4) collaborative interaction (with at least two users). In each case, three scientific challenges arise which correspond to the three successive steps of the 3D interaction loop (blue squares, top): 1) the 3D interaction technique, 2) the modeling and simulation of the 3D scenario, and 3) the design of appropriate sensory feedback.

The 3D interaction loop involves various possible inputs from the user(s) and different kinds of output (or sensory feedback) from the simulated environment. Each user can involve his/her body and mind by means of corporal and/or brain-computer interfaces. A hybrid 3D interaction technique (1) mixes mental and motor inputs and translates them into a command for the virtual environment. The real-time simulation (2) of the virtual environment is taking into account these commands to change and update the state of the virtual world and virtual objects. The state changes are sent back to the user and perceived by means of different sensory feedbacks (e.g., visual, haptic and/or auditory) (3). The sensory feedbacks are closing the 3D interaction loop. Other users can also interact with the virtual environment using the same procedure, and can eventually “collaborate” by means of “collaborative interactive techniques” (4).

This description is stressing three major challenges which correspond to three mandatory steps when designing 3D interaction with virtual environments:

- **3D interaction techniques:** This first step consists in translating the actions or intentions of the user (inputs) into an explicit command for the virtual environment. In virtual reality, the classical tasks that require such kinds of user command were early categorized in four [58]: navigating the virtual world, selecting a virtual object, manipulating it, or controlling the application (entering text, activating options, etc). The addition of a third dimension, the use of stereoscopic rendering and the use of advanced VR interfaces make however inappropriate many techniques that proved efficient in 2D, and make it necessary to design specific interaction techniques and adapted tools. This challenge is here renewed by the various kinds of 3D interaction which are targeted. In our case, we consider various cases, with motor and/or cerebral inputs, and potentially multiple users.

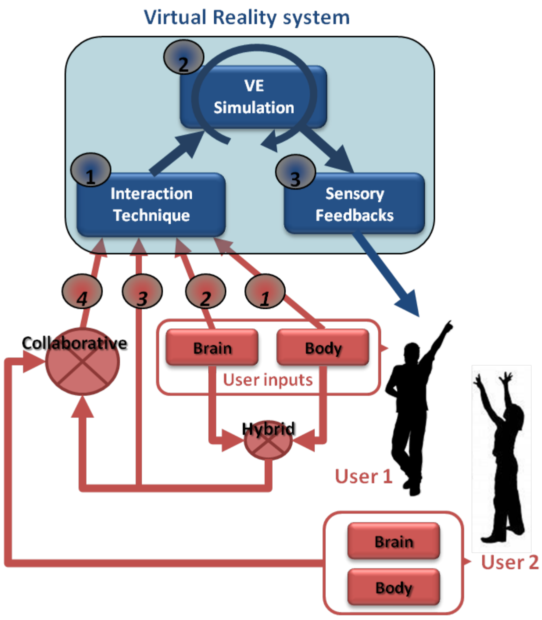


*Figure 1. 3D hybrid interaction loop between one or multiple users and a virtual reality system. Top (in blue) three steps of 3D interaction with a virtual environment: (1) interaction technique, (2) simulation of the virtual environment, (3) sensory feedbacks. Bottom (in red) different cases of interaction: (1) body-based, (2) mind-based, (3) hybrid, and (4) collaborative 3D interaction.*

- **Modeling and simulation of complex 3D scenarios:** This second step corresponds to the update of the state of the virtual environment, in real-time, in response to all the potential commands or actions sent by the user. The complexity of the data and phenomena involved in 3D scenarios is constantly increasing. It corresponds for instance to the multiple states of the entities present in the simulation (rigid, articulated, deformable, fluids, which can constitute both the user's virtual body and the different manipulated objects), and the multiple physical phenomena implied by natural human interactions (squeezing, breaking, melting, etc). The challenge consists here in modeling and simulating these complex 3D scenarios and meeting, at the same time, two strong constraints of virtual reality systems: performance (real-time and interactivity) and genericity (e.g., multi-resolution, multi-modal, multi-platform, etc).
- **Immersive sensory feedbacks:** This third step corresponds to the display of the multiple sensory feedbacks (output) coming from the various VR interfaces. These feedbacks enable the user to perceive the changes occurring in the virtual environment. They are closing the 3D interaction loop, making the user immersed, and potentially generating a subsequent feeling of presence. Among the various VR interfaces which have been developed so far we can stress two kinds of sensory feedback: visual feedback (3D stereoscopic images using projection-based systems such as CAVE systems or Head Mounted Displays); and haptic feedback (related to the sense of touch and to tactile or force-feedback devices). The Hybrid team has a strong expertize in haptic feedback, and in the design of haptic and "pseudo-haptic" rendering [59]. Note that a major trend in the community, which is strongly supported by the Hybrid team, relates to a "perception-based" approach, which aims at designing sensory feedbacks which are well in line with human perceptual capacities.

These three scientific challenges are addressed differently according to the context and the user inputs involved. We propose to consider three different contexts, which correspond to the three different research axes of the Hybrid research team, namely : 1) body-based interaction (motor input only), 2) mind-based interaction (cerebral input only), and then 3) hybrid and collaborative interaction (i.e., the mixing of body and brain inputs from one or multiple users).

## 3.2. Research Axes

The scientific activity of Hybrid team follows three main axes of research:

- **Body-based interaction in virtual reality.** Our first research axis concerns the design of immersive and effective "body-based" 3D interactions, i.e., relying on a physical engagement of the user's body. This trend is probably the most popular one in VR research at the moment. Most VR setups make use of tracking systems which measure specific positions or actions of the user in order to interact with a virtual environment. However, in recent years, novel options have emerged for measuring "full-body" movements or other, even less conventional, inputs (e.g. body equilibrium). In this first research axis we are thus concerned by the emergence of new kinds of "body-based interaction" with virtual environments. This implies the design of novel 3D user interfaces and novel 3D interactive techniques, novel simulation models and techniques, and novel sensory feedbacks for body-based interaction with virtual worlds. It involves real-time physical simulation of complex interactive phenomena, and the design of corresponding haptic and pseudo-haptic feedback.
- **Mind-based interaction in virtual reality.** Our second research axis concerns the design of immersive and effective "mind-based" 3D interactions in Virtual Reality. Mind-based interaction with virtual environments is making use of Brain-Computer Interface technology. This technology corresponds to the direct use of brain signals to send "mental commands" to an automated system such as a robot, a prosthesis, or a virtual environment. BCI is a rapidly growing area of research and several impressive prototypes are already available. However, the emergence of such a novel user input is also calling for novel and dedicated 3D user interfaces. This implies to study the extension of the mental vocabulary available for 3D interaction with VE, then the design of specific 3D interaction techniques "driven by the mind" and, last, the design of immersive sensory feedbacks that could help improving the learning of brain control in VR.

- **Hybrid and collaborative 3D interaction.** Our third research axis intends to study the combination of motor and mental inputs in VR, for one or multiple users. This concerns the design of mixed systems, with potentially collaborative scenarios involving multiple users, and thus, multiple bodies and multiple brains sharing the same VE. This research axis therefore involves two interdependent topics: 1) collaborative virtual environments, and 2) hybrid interaction. It should end up with collaborative virtual environments with multiple users, and shared systems with body and mind inputs.

# 4. Application Domains

## 4.1. Overview

The research program of Hybrid team aims at next generations of virtual reality and 3D user interfaces which could possibly address both the "body" and "mind" of the user. Novel interaction schemes are designed, for one or multiple users. We target better integrated systems and more compelling user experiences.

The applications of our research program correspond to the applications of virtual reality technologies which could benefit from the addition of novel body-based or mind-based interaction capabilities:

- **Industry**: with training systems, virtual prototyping, or scientific visualization;
- **Medicine**: with rehabilitation and reeducation systems, or surgical training simulators;
- **Entertainment**: with 3D web navigations, video games, or attractions in theme parks,
- **Construction**: with virtual mock-ups design and review, or historical/architectural visits.

# 5. Software and Platforms

## 5.1. OpenViBE

**Participants:** Anatole Lécuyer [contact], Jozef Legény, Jussi Lindgren.

OpenViBE is a free and open-source software platform devoted to the design, test and use of Brain-Computer Interfaces (BCI). The platform consists of a set of software modules that can be integrated easily and efficiently to design BCI applications. The key features of OpenViBE software are its modularity, its high-performance, its portability, its multiple-users facilities and its connection with high-end/VR displays. The "designer" of the platform enables to build complete scenarios based on existing software modules using a dedicated graphical language and a simple Graphical User Interface (GUI). This software is available on the Inria Forge under the terms of the AGPL licence, and it was officially released in June 2009. Since then, the OpenViBE software has already been downloaded more than 12000 times, and it is used by numerous laboratories, projects, or individuals worldwide. The OpenViBE software is supported and improved in the frame of OpenViBE-NT project (section 8.2.9). More information, downloads, tutorials, videos, documentations are available on the OpenViBE website.

## 5.2. GVT

**Participants:** Bruno Arnaldi, Valérie Gouranton [contact], Florian Nouviale, Thomas Lopez.

The aim of GVT software (Generic Virtual Training) is to offer personalizable VR training sessions for industrial equipments. The main features of GVT software are the safeness offered by VR training (as opposed to trainind in risky real conditions), the optimization of the learning process, the creation of dedicated scenarios runnable on multiple hardware configurations: laptop or desktop computer, immersive room, distribution over network, etc. The current kernel of the GVT platform is divided into two main elements that rely on innovative models we have proposed: LORA (Language for Object-Relation Application) and STORM (Simulation and Training Object-Relation Model) models. With GVT behavioral engine, the objects of the virtual world expose behavorial capacities through the use of STORM. Then, the GVT scenario engine is used to determine the next steps of the procedure for a trainee, and its state evolves as the trainees achieve some actions, the scenario being written in LORA. As for today, a commercialized version of GVT, which includes a pedagogical engine developed at CERV laboratory, proposes training on individual procedures. In CORVETTE (section 8.2.1) and SIFORAS (section 8.2.6) projects, new features based on GVT are being designed, such as interactive, collaborative and physicalized actions, actors knowledge management, dialog using natural langage.

## 5.3. Collaviz

**Participants:** Thierry Duval [contact], Thi Thuong Huyen Nguyen.

The aim of Collaviz software (collaborative interactive visualization) is to allow to design, deploy and share collaborative virtual environments (CVE). Collaviz allows VR developpers to concentrate on the behavior of virtual objects that can be shared between users in a CVE. Indeed, Collaviz provides a software architecture that hides the network programmation details of the distribution and the synchronization of the content of the CVE, and that facilitates the coupling with the 3D graphics API used for rendering. Collaviz is written mainly in Java and is runnable on multiple hardware configurations: laptop or desktop computer, immersive room, mobile devices. The PAC-C3D software architecture of Collaviz makes it possible to use various 3D APIs for graphic rendering: Java3D, jReality, jMonkeyEngine, OpenSG, Unity3D (work in progress) and Havok Anarchy (work in progress), and also to use various physical engines such as jBullet and SOFA. The distribution over the network can be achieved using TCP or HTTP. An on-going collaboration with Triskell team intends to extend Collaviz using a Model Driven Engineering approach in order to provide high-level tools to generate a large part of java code of virtual objects.

# 6. New Results

## 6.1. 3D interactive techniques

### *6.1.1. Navigating in virtual environments with omnidirectional rendering*

**Participants:** Jérôme Ardouin [contact], Anatole Lécuyer [contact], Maud Marchal.

The “FlyVIZ” enables humans to experience a real-time 360o vision of their surroundings for the first time. The visualization device combines a panoramic image acquisition system (positioned on top of the user’s head) with a Head-Mounted Display (HMD). The omnidirectional images are transformed to fit the characteristics of HMD screens. As a result, the user can see his/her surroundings, in real-time, with 360o images mapped into the HMD field-of- view.

In order to safely simulate and evaluate our approach, we designed and evaluated [28] several visualization techniques, for navigating in virtual environments (VE). We have conducted an evaluation of different methods compared to a rendering method of reference, i.e. a perspective projection, in a basic navigation task. Our results confirm that using any omnidirectional rendering method could lead to more efficient navigation in terms of average task completion time. Among the different 360o projection methods, the subjective preference was significantly given to a cylindrical projection method (equirectangular). Taken together, our results suggest that omnidirectional rendering could be used in virtual reality applications in which fast navigation or full and rapid visual exploration are important. They pave the way to novel kinds of visual cues and visual rendering methods in virtual reality. This work was a collaboration with the Lagadic team (Inria Rennes).

*Figure 2. The “FlyVIZ” enables humans to experience in real-time a 360-degree vision of their surroundings.*

### 6.1.2. Advances in locomotion interfaces for virtual environments

**Participants:** Anatole Lécuyer [contact], Maud Marchal [contact], Bruno Arnaldi.

Navigation, a fundamental task in Virtual Reality (VR), is greatly influenced by the locomotion interface being used, by the specificities of input and output devices, and by the way the virtual environment is represented. No matter how virtual walking is controlled, the generation of realistic virtual trajectories is absolutely required for some applications, especially those dedicated to the study of walking behaviors in VR, navigation through virtual places for architecture, rehabilitation and training.

First, we have studied the realism of unconstrained trajectories produced during virtual walking.We proposed a comprehensive evaluation framework consisting on a set of trajecto-graphical criteria and a locomotion model to generate reference trajectories [17]. We considered a simple locomotion task where users walk between two oriented points in space. The travel path was analyzed both geometrically and temporally in comparison to simulated reference trajectories. This work was a collaboration with the Mimetic team (Inria Rennes).

Secondly, we have introduced novel “Camera Motions” (CMs) to improve the sensations related to locomotion in virtual environments (VE) [27]. Traditional CMs are artificial oscillating motions applied to the subjective viewpoint when walking in the VE, and they are meant to evoke and reproduce the visual flow generated during a human walk. Our novel CMs are: (1) multistate, (2) personified, and (3) they can take into account the topography of the virtual terrain. In addition, they can then take into account avatar’s fatigue and recuperation, and the topography for updating visual CMs accordingly. Taken together, our results suggest that our new CMs could be introduced in Desktop VR applications involving first-person navigation, in order to enhance sensations of walking, running, and sprinting, with potentially different avatars and over uneven terrains, such as for training, virtual visits or video games.

### 6.1.3. 3D manipulation of virtual objects: 3-Point++

**Participants:** Thierry Duval [contact], Thi Thuong Huyen Nguyen.

Manipulation in immersive Virtual Environments (VEs) is often difficult and inaccurate because humans have difficulty in performing precise positioning tasks or in keeping the hand motionless in a particular position without any help of external devices or haptic feedback. To address this problem, we proposed a set of four manipulation points attached to objects (called a 3-Point++ tool, including three handle points and their barycenter), by which users can control and adjust the position of objects precisely [40]. By determining the relative position between the 3-Point++ tool and the objects, and by defining different states of each manipulation point (called locked/unlocked or inactive/active), these points can be freely configured to be adaptable and flexible to enable users to manipulate objects of varying sizes in many kinds of positioning scenarios.

### 6.1.4. A survey of 3D object selection techniques for virtual environments

**Participant:** Ferran Argelaguet Sanz [contact].

Computer graphics applications controlled through natural gestures are gaining increasing popularity these days due to recent developments in low-cost tracking systems and gesture recognition technologies. Although interaction techniques through naturalgestures have already demonstrated their benefits in manipulation, navigation and avatar-control tasks, effective selection with pointing gestures remains an open problem. We surveyed the state-of-the-art in 3D object selection techniques [13]. We reviewed important findings in human control models, analyze major factors influencing selection performance, and classify existing techniques according to a number of criteria. Unlike other components of the application's user interface, pointing techniques need a close coupling with the rendering pipeline, introducing new elements to be drawn, and potentially modifying the object layout and the way the scene is rendered. Conversely, selection performance is affected by rendering issues such as visual feedback, depth perception, and occlusion management. We thus reviewed existing literature paying special attention to those aspects in the boundary between computer graphics and human computer interaction.

### *6.1.5. Novel pseudo-haptic based interfaces*

**Participants:** Pierre Gaucher, Ferran Argelaguet Sanz, Anatole Lécuyer [contact], Maud Marchal.

Pseudo-haptics is a technique meant to simulate haptic sensations using visual feedback and properties of human visuo-haptic perception. In this course of action, we have extended its usage for gestural interfaces [33] and exploring its usage for the simulation of the local elasticity of images [14].

Interacting with virtual objects through free-hand gestures do not allow users to perceive the physical properties of virtual objects. To provide enhanced interaction, we explored how the usage of a pseudo-haptic approach could be introduced while interacting with a 3D Carrousel [33]. In our approach, which is envisioned for showcasting purposes, virtual products are presented using a 3D carousel augmented with physical behavior and a pseudo-haptic effect aiming to attract the user to specific items. The user, through simple gestures, controls the rotation of the carousel, and can select, examine and manipulate the objects presented. Several demos can be tested on-line at Hybrid website.

Secondly, we have introduced the Elastic Images, a novel pseudo-haptic feedback technique which enables the perception of the local elasticity of images without the need of any haptic device [14]. The proposed approach focuses on whether visual feedback is able to induce a sensation of stiffness when the user interacts with an image using a standard mouse. The user, when clicking on a Elastic Image, is able to deform it locally according to its elastic properties. A psychophysical experiment was conducted to quantify this novel pseudo-haptic perception and determine its perceptual threshold (or its Just Noticeable Difference). The results showed that users were able to recognize up to eight different stiffness values with our method and confirmed that it provides a perceivable and exploitable sensation of elasticity.

### *6.1.6. Experiencing the past in virtual reality*

**Participant:** Valérie Gouranton [contact].

We designed a public experience and exhibition organized during the French National Days of Archaeology. This was the result of an interdisciplinary collaboration between archaeologists and computer scientists, centered on the immersive virtual reality platform Immersia, a node of the European Visionair project. This public exhibition had three main goals: (i) presenting our interdisciplinary collaboration, (ii) communicating on the scientific results of this collaboration, and (iii) offering an immersive experience in the past for visitors. In [34] we could present the scientific context of the event, its organization, and a discussion on feedbacks.

In the frame of the CNPAO project (section 8.1.3) we have also worked on the reconstitution of six archaeological sites located in the west of France ranging from prehistory to the Middle Ages: the Cairn of Carn Island, the covered pathway of Roh Coh Coet, the GohMin Ru megalithic site, the gallo-roman mansion of Vanesia, the keep of the Château de Sainte-Suzanne, the Porte des Champs of the Château d'Angers. Other proposals are currently under study [30].

### *6.1.7. Perception of affordances in virtual reality*

**Participants:** Anatole Lécuyer [contact], Maud Marchal.

*Figure 3. "Touching the past" experience during the French National Days of Archaeology.*

The perception of affordances could be a potential tool for sensorimotor assessment of physical presence, that is, the feeling of being physically located in a virtual place. We have evaluated the perception of affordances for standing on a virtual slanted surface [26]. Participants were asked to judge whether a virtual slanted surface supported up right stance. The objective was to evaluate if this perception was possible in virtual reality (VR) and comparable to previous works conducted in real environments. We found that the perception of affordances for standing on a slanted surface in virtual reality is possible and comparable (with an underestimation) to previous studies conducted in real environments. We also found that participants were able to extract and to use virtual information about friction in order to judge whether a slanted surface supported an upright stance. Finally, results revealed that the person's position on the slanted surface is involved in the perception of affordances for standing on virtual grounds. Taken together, our results show quantitatively that the perception of affordances can be effective in virtual environments, and influenced by both environmental and person properties. Such a perceptual evaluation of affordances in VR could guide VE designers to improve their designs and to better understand the effect of these designs on VE users.

## 6.2. Haptic Feedback and Physical Simulation

### *6.2.1. Haptic feedback to improve audiovisual experience*

**Participants:** Fabien Danieau, Anatole Lécuyer [contact].

Haptics have been employed in a wide set of applications ranging from teleoperation and medical simulation to arts and design, including entertainment, aircraft simulation and virtual reality. As for today, there is also a growing attention from the research community on how haptic feedback can be integrated with profit to audiovisual systems. We have first reviewed [19] the techniques, formalisms and key results on the enhancement of audiovisual experience with haptic feedback. We first reviewed the three main stages in the pipeline which are (i) production of haptic effects, (ii) distribution of haptic effects and (iii) rendering of haptic effects. We then highlighted the strong necessity for evaluation techniques in this context and discuss the key challenges in the field. By building on technology and results from virtual reality, and tackling the specific challenges in the enhancement of audiovisual experience with haptics, we believe the field presents exciting research perspectives for which financial and societal stakes are significant.

We have then developped a novel approach called HapSeat for simulating motion sensations in a consumer environment.Multiple force-feedbacks are applied to the seated user's body to generate a 6DoF sensation of motion while experiencing passive navigation as illustrated Figure 4. A set of force-feedback devices such as mobile armrests or headrests are arranged around a seat so that they can apply forces to the user. The forces are computed consistently with the visual content (visual acceleration) in order to generate motion sensations. This novel display device has been patented and was demonstrated this year at ACM SIGGRAPH 2013 Emerging-Technologies [56], and ACM CHI 2013 Interactivity [55].

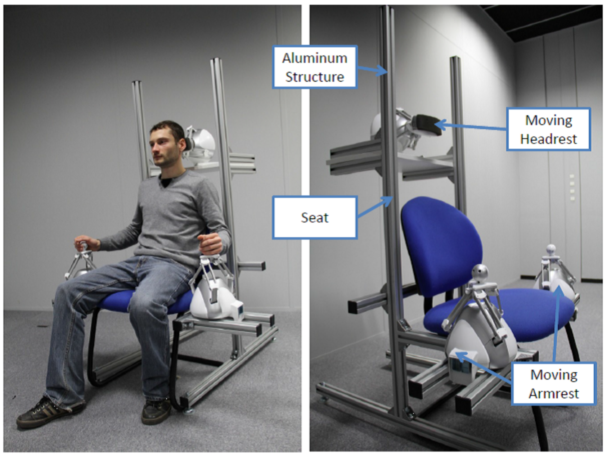


*Figure 4. The HapSeat device: force-feedback is applied on the user's body with mobile armrests or headrests in order to generate motion sensations that are consistent with the visual content.*

This work was a collaboration with the Mimetic team (Inria Rennes).

### 6.2.2. Vibrotactile rendering of splashing fluids

**Participants:** Anatole Lécuyer, Maud Marchal [contact].

Compelling virtual reality scenarios involving physically based virtual materials have been demonstrated using hand- based and foot-based interaction with visual and vibrotactile feedback. However, some materials, such as water and other fluids, have been largely ignored in this context. For VR simulations of real-world environments, the inability to include interaction with fluids is a significant limitation. Potential applications include improved training involving fluids, such as medical and phobia simulators, and enhanced user experience in entertainment, such as when interacting with water in immersive virtual worlds. We introduced the use of vibrotactile feedback as a rendering modality for solid-fluid interaction, based on the physical processes that generate sound during such interactions [16]. This rendering approach enables the perception of vibrotactile feedback from virtual scenarios that resemble the experience of stepping into a water puddle or plunging a hand into a volume of fluid.

### 6.2.3. Six-DoF haptic interaction with fluids, solids, and their transitions

**Participants:** Anatole Lécuyer, Maud Marchal [contact].

Haptic interaction with different types of materials in the same scene is a challenging task, mainly due to the specific coupling mechanisms that are usually required for either fluid, deformable or rigid media. Dynamically-changing materials, such as melting or freezing objects, present additional challenges by adding another layer of complexity in the interaction between the scene and the haptic proxy. We have addressed these issues through a common simulation framework, based on Smoothed-Particle Hydrodynamics, and enable haptic interaction simultaneously with fluid, elastic and rigid bodies, as well as their melting or freezing [31]. We introduced a mechanism to deal with state changes, allowing the perception of haptic feedback during the process, and a set of dynamic mechanisms to enrich the interaction through the proxy. We decouple the haptic and visual loops through a dual GPU implementation. An initial evaluation of the approach was performed through performance and feedback measurements, as well as a small user study assessing the capability of users to recognize the different states of matter they interact with.

### 6.2.4. Bimanual haptic manipulation

**Participants:** Anatole Lécuyer [contact], Maud Marchal [contact], Anthony Talvas.

Bimanual haptics is a specific kind of multi-finger interaction that focuses on the use of both hands simultaneously. Several haptic devices enable bimanual haptic interaction, but they are subject to a certain number of limitations for interacting with virtual environments (VEs), such as workspace size issues or manipulation difficulties, notably with single-point interfaces. Interaction techniques exist to overcome these limitations and allow users to perform specific two-handed tasks, such as the bimanual exploration of large VEs and grasping of virtual objects. We have proposed an overview of the current limitations in bimanual haptics and the interaction techniques developed to overcome them. Novel techniques based on the Bubble technique are more specifically presented, with a user evaluation that assesses their efficiency. These include bimanual workspace extension techniques as well as techniques to improve the grasping of virtual objects with dual single-point interfaces. This work was published as a chapter in a book on “Multi-finger Haptic Interaction” [52].

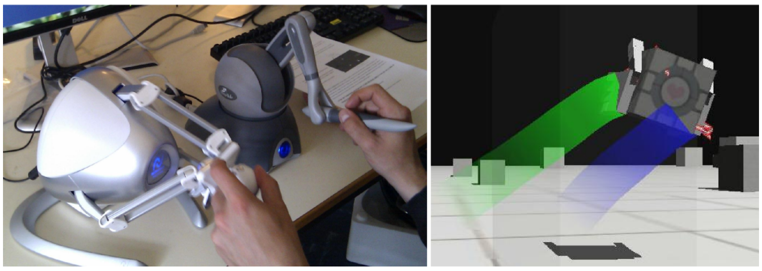

*Figure 5. 3D interaction techniques for bimanual haptic manipulation.*

### 6.2.5. The god-finger method

**Participants:** Anatole Lécuyer, Maud Marchal [contact], Anthony Talvas.

In physically-based virtual environments, interaction with objects generally happens through contact points that barely represent the area of contact between the user’s hand and the virtual object. This representation of contacts contrasts with real life situations where our finger pads have the ability to deform slightly to match the shape of a touched object. We have proposed a method called god-finger to simulate a contact area from a single contact point determined by collision detection, and usable in a rigid body physics engine [43]. The method uses the geometry of the object and the force applied to it to determine additional contact points that will emulate the presence of a contact area between the user’s proxy and the virtual object. It could improve the manipulation of objects by constraining the rotation of touched objects in a similar manner to actual finger pads. An implementation in a physics engine shows that the method could make for more realistic behaviour when manipulating objects while keeping high simulation rates. This work was presented at IEEE 3DUI Symposium 2013 and has received the best technote award [43].

### 6.2.6. Collision detection for fracturing rigid bodies

**Participant:** Maud Marchal [contact].

In complex scenes with many objects, collision detection plays a key role in the simulation performance. This is particularly true for fracture simulation, where multiple new objects are dynamically created. We have proposed novel algorithms and data structures for collision detection in real-time brittle fracture simulations [22]. We build on a combination of well-known efficient data structures, namely distance fields and sphere trees, making our algorithm easy to integrate on existing simulation engines. We proposed novel methods to construct these data structures, such that they can be efficiently updated upon fracture events and integrated in a simple yet effective self-adapting contact selection algorithm. Altogether, we drastically reduced the cost of both collision detection and collision response. We have evaluated our global solution for collision detection on challenging scenarios, achieving high frame rates suited for hard real-time applications such as video games or haptics. Our solution opens promising perspectives for complex brittle fracture simulations involving many dynamically created objects.

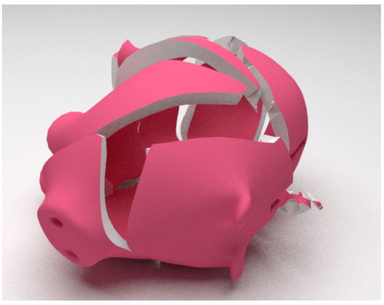

*Figure 6. Example of brittle fracture with collision detection.*

This work was a collaboration with the Mimetic team (Inria Rennes).

#### 6.2.7. Collision detection with high performance computing on GPU

**Participants:** Bruno Arnaldi, Valérie Gouranton [contact], François Lehericey.

We have first proposed IRTCD, a novel Iterative Ray-Traced Collision Detection algorithm that exploits spatial and temporal coherency. Our approach uses any existing standard ray-tracing algorithm and we propose an iterative algorithm that updates the previous time step results at a lower cost with some approximations. Applied for rigid bodies, our iterative algorithm accelerate the collision detection by a speedup up to 33 times compared to non-iterative algorithms on GPU [35].

Then, we have presented two methods to efficiently control and reduce the interpenetration without noticeable computation overhead. The first method predicts the next potentially colliding vertices. These predictions are used to make our IRTCD algorithm more robust to the approximations, therefore reducing the errors up to 91%. We also present a ray re-projection algorithm that improves the physical response of ray-traced collision detection algorithm. This algorithm also reduces, up to 52%, the interpenetration between objects in a virtual environment. Our last contribution showed that our algorithm, when implemented on multi-GPUs architectures, is far faster [36].

Finally, we proposed a distributed and anticipative model for collision detection and propose a lead for distributed collision handling, two key components of physically-based simulations of virtual environments. This model is designed to improve the scalability of interactive deterministic simulations on distributed systems such as PC clusters. Our main contribution consists of loosening synchronism constraints in the collision detection and response pipeline to allow the simulation to run in a decentralized, distributed fashion. We could show the potential for distributed load balancing strategies based on the exchange of grid cells, and explain how anticipative computing may, in cases of short computational peaks, improve user experience by avoiding frame-rate drop-downs [32].

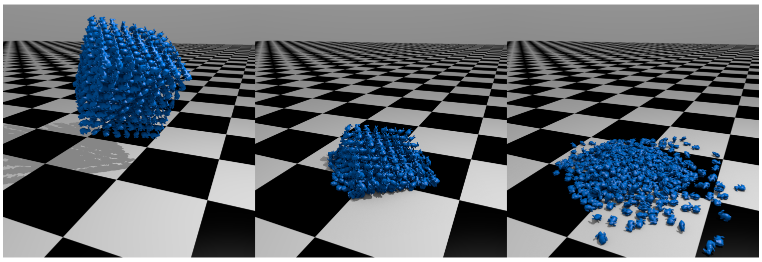

*Figure 7. Real-time simulation of iterative ray-traced collision detection algorithm.*

## 6.3. Brain-Computer Interfaces and Virtual Environments

### *6.3.1. Multi-user BCI video game*

**Participant:** Anatole Lécuyer [contact].

How can we connect two brains to a video game by means of a BCI, and what will happen when we do so? How will the two users behave, and how will they perceive this novel common experience? We have created a multi-user videogame called “BrainArena” in which two users can play a simple football game by means of two BCIs [15], as illustrated Figure 8. They can score goals on the left or right side of the screen by simply imagining left or right hand movements. To add another interesting element , the gamers can play in a collaborative manner (their two mental activities are combined to score in the same goal), or in a competitive manner (the gamers must push the ball in opposite directions). Two experiments were conducted to evaluate the performance and subjective experience of users in the different conditions. Taken together our results suggest that multi-user BCI applications can be operational, effective, and more engaging for participants.

This work was a collaboration with the Potioc team (Inria Bordeaux).

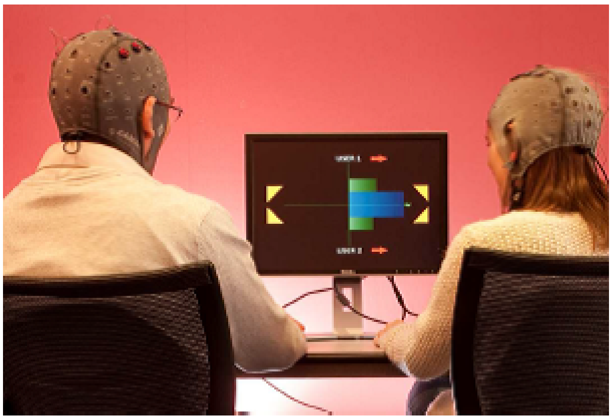

*Figure 8. Multi-user football videogame in which two players can score goals to the left or right by imagining left or right hand movements. The users can play together using their brain activities either in a collaboration mode (same goal) or in a competitive mode (one versus the other).*

### 6.3.2. Contextual SSVEP-based BCI control

**Participants:** Jozef Legény, Anatole Lécuyer [contact].

One main disadvantage of Brain-Computer Interfaces is that they are not completely reliable. In order to increase BCI performances, some adjustments can be made on low levels, such as signal processing and on high levels by modifying the controller paradigm. We have explored a novel, context-dependent, approach for SSVEP-based BCI controller [23]. This controller uses two kinds of behaviour alternation, commands can be added and removed if their use is irrelevant to the context or the actions resulting from their activation can be weighted depending on the likeliness of the actual intention of the user. This controller has been integrated within a BCI computer game and its influence in performance and mental workload has been addressed through a pilot experiment. Preliminary results have shown a workload reduction and performance improvement with the context-dependent controller while keeping the engagement levels untouched.

This work was a collaboration with the Universidad de Jaen (Spain).

### 6.3.3. Can we use a BCI and manipulate a mouse at the same time?

**Participants:** Jonathan Mercier-Ganady, Anatole Lécuyer [contact], Maud Marchal.

In most setups using a BCI, the user is explicitly asked to remain as motionless as possible, since muscular activity is commonly admitted to add noise and artifacts in brain electrical signals. Thus, as for today, people have been rarely let using other classical input devices such as mice or joysticks simultaneously to a BCI-based interaction. We have conducted an experimental study on the influence of manipulating an input device such as a standard computer mouse on the performance of a BCI system [38]. The study uses a simple virtual environment inspired by the well-known Pac-Man videogame and based on BCI and mouse controls. As expected the BCI performance was found to slightly decrease in presence of motor activity. However, we found that the BCI could still be successfully used in all conditions, even in presence of a highly-demanding mouse manipulation. These promising results pave the way to future experimental studies with more complex mental and motor activities, but also to novel 3D interaction paradigms that could mix BCI and other input devices for virtual reality and videogame applications.

### 6.3.4. Adaptive VR simulators combining visual, haptic, and BCIs

**Participants:** Anatole Lécuyer [contact], Maud Marchal.

What if the next generation of virtual reality simulators would take into account a novel user's input: his/her mental state, as measured with electrodes and Brain-Computer Interfaces ? This would lead to adaptive simulators that could match the "hidden" expectations of the user optimally? We have initiated and illustrated this promising path with a virtual reality setup in which the force-feedback of a guidance system is adapted in real-time to the "mental workload" of the user [24]. A first application of this approach is a medical simulator in which virtual assistances are automatically adapted to surgeon and trainee's mental activity as illustrated Figure 9. Such results pave the way to future virtual reality systems which would automatically reconfigure and adapt to cerebral inputs and cognitive processes.

## 6.4. Collaborative Virtual Environments

### 6.4.1. Collaborative exploration in multi-scale shared virtual environments

**Participants:** Thierry Duval [contact], Thi Thuong Huyen Nguyen.

Exploration of large-scale 3D Virtual Environments (VEs) is often difficult because of lack of familiarity with complex virtual worlds, lack of spatial information that can be offered to users and lack of sensory details compared to the exploration of real environments. To address this problem, we presented a set of metaphors for assisting users in collaborative navigation to perform common exploration tasks in shared collaborative virtual environments [39], [57]. Our propositions consist in three guiding techniques in the form of navigation aids to enable one or several users to help one main user (exploring user) to explore the VE efficiently. These three techniques consist in drawing directional arrows, lighting up path to follow, and orienting a compass to show a direction to the exploring user. Our experimental results could show that although the directional arrows and compass surpassed the light source in a navigation task, these three techniques are completely appropriate for guiding a user in 3D complex VEs.

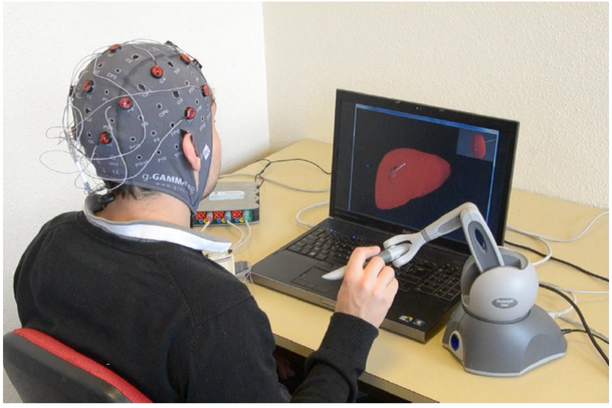

*Figure 9. Medical simulator adapted to a BCI output. The user manipulates a virtual needle and has to insert it into a virtual liver to reach a tumor. Visual and haptic assistances are activated when a high mental workload is detected which corresponds to a more difficult manipulation of the needle.*

### 6.4.2. Improving the awareness of collaboration in 3D virtual environments

**Participants:** Thierry Duval [contact], Thi Thuong Huyen Nguyen, Valérie Gouranton.

When a user is fully immersed within a Virtual Environments (VE) through a large immersive display system, his feeling of presence can be altered because of disturbing interactions with his physical environment, such as collision with hardware parts of the system or loss of tracking. This alteration can be avoided by taking into account the physical features of the user and to embed them in the VE. In [20] we could present how we use the Immersive Interactive Virtual Cabin (IIVC) model to obtain such a virtual representation of the physical environment of the user and we illustrated how it can be used to guide efficiently a user for a navigation task in a VE. We also presented how we can add 3D representations of 2D interaction tools in order to cope with asymmetrical collaborative configurations, providing 3D cues for users in order to understand the actions of the other users even if they are not fully immersed in the shared virtual environment. Last, we explained how we could enhance 3D interaction and collaboration by embedding a symbolic 3D representation of the user that would give 3D information about his posture.

### 6.4.3. Sharing and bridging information: application to ergonomics

**Participant:** Thierry Duval [contact].

We introduced a collaborative virtual environment usable to conduct ergonomic design sessions, involving the worker, ergonomists and engineers [41]. We focused particularly on the representation of the ergonomic evaluation and the interaction between an ergonomist and the main user (worker). An ergonomic evaluation of the postures was presented. An interaction architecture between the main user and an ergonomist based on the combination of animation modes of two linked manikins was also proposed. Preliminary results and future developments of the CVE (e.g. additional ergonomic evaluation tools, graphical enhancement, interaction enhancement) were then presented.

### 6.4.4. User embodiment and collaboration in virtual environments for training

**Participants:** Bruno Arnaldi, Valérie Gouranton [contact], Thomas Lopez, Florian Nouviale, Rozenn Bouville Berthelot.

In Collaborative Virtual Environments for Training (CVET), a group can learn and practice the completion of a task as a team using all the assets provided by Virtual Reality. We presented a novel mechanism that allows real and virtual humans to dynamically exchange the control of their embodiment in virtual environments [42]. Such a mechanism raises two important issues: the possibility of dynamic embodiment exchanges between real humans and virtual humans and the continuity of actions of the team members after an exchange. To address these issues we introduce a new entity, the Perceptive Puppet that abstracts real and virtual humans into one common entity containing its own knowledge.

In addition, in CVET different roles need to be played by actors, i.e. virtual agents or users. In order to abstract an actor from its embodiment in the virtual world, we have introduced a new entity, the Shell [37]. Through the Shell, users and virtual agents are able to collaborate in the same manner during the training. In addition to the embodiment's control, the Shell gathers and carries knowledge and provides interaction inputs. This knowledge and those inputs can be accessed and used homogeneously by both users and virtual agents to help them to perform the procedure.

# 7. Bilateral Contracts and Grants with Industry

## 7.1. Bilateral Grants with Industry

### *7.1.1. Orange Labs*

**Participants:** Pierre Gaucher, Anatole Lécuyer.

This grant started in October 2012 and supported Pierre Gaucher's CIFRE PhD program on "Novel 3D interaction techniques based on pseudo-haptic feedback".

### *7.1.2. Technicolor*

**Participants:** Fabien Danieau, Anatole Lécuyer.

This grant started in January 2011 and supported Fabien Danieau's CIFRE PhD program on "Improving audiovisual experience with haptic feedback".

## 7.2. Bilateral Contracts with Industry

### *7.2.1. Mensia Technologies*

**Participants:** Jozef Legény, Jussi Lindgren, Anatole Lécuyer.

Mensia Technologies is an Inria start-up company created in November 2012 as a spin-off of Hybrid team. Mensia is focused on wellness and healthcare applications emerging from the BCI and Neurofeedback technologies. The Mensia startup should benefit from the team's expertise and of valuable and proprietary BCI research results. Mensia is based in Rennes and Paris. Anatole Lécuyer and Yann Renard (former Inria expert engineer who designed the OpenViBE software architecture and was involved in team projects for 5 years) are co-founders of Mensia Technologies together with CEO Jean-Yves Quentel.

The contract between Hybrid and Mensia started in November 2013 and supported the transfer of several softwares designed by Hybrid team ("OpenViBE", "StateFinder") related to our BCI activity and our OpenViBE software (section 5.1) to Mensia Technologies for 5 years, for future multimedia or medical applications of Mensia.

### *7.2.2. MBA Multimedia*

**Participants:** Ferran Argelaguet Sanz, Maud Marchal, Anatole Lécuyer.

This contract started in June 2013 and supported the transfer of several softwares designed by Hybrid team ("3D Cursors", "Elastic Images") in the frame of the W3D project (section 8.1.2) to MBA Multimédia company for future applications in the field of multimedia and web design based mainly on HTML5 and Word Press software.

### *7.2.3. Polymorph Studio*

**Participants:** Ferran Argelaguet Sanz, Maud Marchal, Anatole Lécuyer.

This contract started in June 2013 and supported the transfer of several softwares designed by Hybrid team ("3D Cursors", "Pseudo-haptik", "Elastic Images") in the frame of the W3D project (section 8.1.2) to Polymorph Studio company for future applications in the field of multimedia and web design based mainly on Unity3D software.

# 8. Partnerships and Cooperations

## 8.1. Regional Initiatives

### *8.1.1. BRAINVOX Project*

**Participants:** Anatole Lécuyer [contact], Jozef Legény.

BRAINVOX is a project funded by Brittany region in the frame of the CREATE call. It is a 4-year project (2009-2013) on the topic of Brain-Computer Interfaces. The objective is to reach a "mental vocabulary", more elaborated, and richer, for BCI applications, enabling to exploit various mental activities within novel hybrid schemes.

### *8.1.2. W3D Project*

**Participants:** Ferran Argelaguet Sanz, Anatole Lécuyer [contact], Maud Marchal.

W3D is a project funded by Brittany region and “Images et Réseaux” competitivity cluster. It is a 3-year project (2011-2013) dedicated to the improvement of perception and navigation on 3D Web content. It involves Inria/Hybrid and LOUSTIC lab, and two SMEs in the field of multimedia and web applications : MBA Multimédia and Polymorph Studio.

### *8.1.3. CNPAO Project*

**Participant:** Valérie Gouranton [contact].

CNPAO ("Conservatoire Numérique du Patrimoine Archéologique de l’Ouest") is a research project partially funded by the Université Européenne de Bretagne (UEB). It involves IRISA/Hybrid and CReAAH. The main objectives are: (i) a sustainable and centralized archiving of 2D/3D data produced by the archaeological community, (ii) a free access to metadata, (iii) a secure access to data for the different actors involved in scientific projects, and (iv) the support and advice for these actors in the 3D data production and exploration through the latest digital technologies, modeling tools and virtual reality systems.

### *8.1.4. Labex S3PM*

**Participants:** Bruno Arnaldi [contact], Valérie Gouranton [contact], Guillaume Claude.

S3PM is a 3-year project (2013-2016) funded by Labex CominLabs. It involves 3 academic research teams: Medicis (LTSI/Inserm), S4 and Hybrid (IRISA/Inria). S3PM aims at providing specific models, tools and software to create a collaborative virtual environment dedicated to neurosurgery processes using observations of real processes.

### *8.1.5. Labex HEMISFER*

**Participant:** Anatole Lécuyer [contact].

HEMISFER is a 3-year project (2013-2016) funded by Labex CominLabs. It involves 4 Inria/IRISA teams (Hybrid, Visages (lead), Panama, Athena) and 2 medical centers: the Rennes Psychiatric Hospital (CHGR) and the Reeducation Department of Rennes Hospital (CHU Pontchaillou). The goal of HEMISFER is to make full use of neurofeedback paradigm in the context of rehabilitation and psychiatric disorders. The major breakthrough will come from the use of a coupling model associating functional and metabolic information from Magnetic Resonance Imaging (fMRI) to Electro-encephalography (EEG) to “enhance” the neurofeedback protocol. Clinical applications concern motor, neurological and psychiatric disorders (stroke, attention-deficit disorder, treatment-resistant mood disorders, etc).

## 8.2. National Initiatives

### *8.2.1. ANR CORVETTE*

**Participants:** Bruno Arnaldi [contact], Valérie Gouranton [contact], Florian Nouviale, Thomas Lopez, Rozenn Bouville Berthelot, Thomas Boggini, Quentin Petit.

CORVETTE (COllaboRative Virtual Environment Technical Training and Experiment) is a 4-year ANR project (2011-2014) led by Bruno Arnaldi. It involves 3 Academic partners (INSA Rennes, ENIB, CEA-List) and 4 Industrial partners (AFPA, Nexter Training, Virtualys, Golaem). CORVETTE aims at designing novel approaches for industrial training (maintenance, complex procedures, security, diagnosis, etc) exploiting virtual reality technologies. The project has three main research axes: collaborative work, virtual human, communication and evaluation. The project seeks to put in synergy: 1) Virtual Human for its ability to embody the user as an avatar and acting as a collaborator during trainingj; 2) Natural communication between users and virtual humans for task-oriented dialogues; and 3) Methodologies in cognitive psychology for the assessment of the effectiveness of the collaboration of users and virtual humans to perform complex cooperative tasks in VR. All these components have been integrated into a unified environment based on an industrial scenario. Several evaluations regarding the different technologies developed in the project have also been achieved.


*Figure 10. Exhibition of the CORVETTE project at Laval Virtual 2013.*

### *8.2.2. ANR MANDARIN*

**Participants:** Merwan Achibet, Anatole Lécuyer, Maud Marchal [contact].

MANDARIN ("MANipulation Dextre hAptique pour opéRations INdustrielles en RV") is a 4-year ANR project (2012-2015). MANDARIN partners are CEA-List (coordinator), Inria/Hybrid, UTC, Haption and Renault. It aims at designing new hardware and software solutions to achieve natural and intuitive mono and bi-manual dextrous interactions, suitable for virtual environments. The objective of Hybrid in MANDARIN is to design novel multimodal 3D interaction techniques and metaphors allowing to deal with haptic gloves limitations (portability, under-actuation) and to assist the user in virtual reality applications requiring dexterous manipulation. The results will be evaluated with a representative industrial application which is not feasible with currently existing technologies: the bi-manual manipulation of complex rigid objects and cables bundles.

### *8.2.3. ANR HOMO-TEXTILUS*

**Participants:** Anatole Lécuyer [contact], Maud Marchal, Jonathan Mercier-Ganady.

HOMO-TEXTILUS is a 4-year ANR project (2012-2015). Partners of the project are : Inria/Hybrid, CHART, LIP6, TOMORROW LAND, RCP and potential end-user is Hussein Chalayan fashion designer. The objective of HOMO TEXTILUS is to study what could be the next generation of smart and augmented clothes, and their influence and potential impact on behavior and habits of their users. The project is strongly oriented towards human science, with both user studies and sociological studies. The involvement of Hybrid team in the project consists in studying the design of next-gen prototypes of clothes embedding novel kinds of sensors and actuators. Envisionned sensors relate to physiological measurements such as with EEG (electroencephalograpohy and Brain-Computer Interfaces), EMG (muscular activity), GSR (galvanic skin response) or Heart Rate (HR). Envisionned actuators relate to new sensory stimulations such as vibrotactile displays or novel visual (eg LED) displays. These prototypes will thus be used in the various experiments planned in the project.

### *8.2.4. ANR ACOUSTIC*

**Participant:** Maud Marchal [contact].

ACOUSTIC is a 3-year ANR project (2011-2013). Partners of the project are : INSERM/University of Rennes 1, CRICM, University of Strasbourg, Inria (Hybrid and Shacra teams). The main objective of the project ACouStiC is to develop an innovative strategy based on models for helping decision-making process during surgical planning in Deep Brain Stimulation. Models rely on different levels involved in the decision-making process; namely multimodal images, information, and knowledge. The project aims at developing methods for 1) building generic and patient specific models and 2) automatically computing optimal electrodes trajectories from these models taking into account possible simulated deformations occurring during surgery. Hybrid is involved in the project with Inria team Shacra and aims at providing models of deformations of the cerebral structures and electrodes for the surgical planning. The objective is to propose a biomechanical approach to model the brain and electrode deformations and also their mutual interaction.

### *8.2.5. ANR OpenViBE2*

**Participants:** Anatole Lécuyer [contact], Jozef Legény, Jonathan Mercier-Ganady.

OpenViBE2 is a 4-year ANR project (2009-2013) led by Anatole Lécuyer which ended in February 2013. Partners of the project were: Inria/Hybrid, INSERM, GIPSA-LAB, CEA, CHART, CLARTE, UBISOFT, BLACK SHEEP, and KYLOTONN GAMES. The objective of OpenViBE2 was to study the potential of Brain-Computer Interfaces (BCI) for videogames. OpenViBE2 has proposed a shift of perspective about the use of BCI. First, in OpenViBE2 we considered the possibility to merge a BCI with traditional peripherals such as joysticks, mice and other devices, all being possibly used simultaneously in a virtual environment. Therefore, BCI was not seen as a replacement but as a complement of classical HCI. Second, we aimed at monitoring brain cognitive functions and mental states of the user in order to adapt, in real-time and in an automated fashion, the interaction protocol as well as the content of the remote/virtual environment (VE).

### *8.2.6. FUI SIFORAS*

**Participants:** Bruno Arnaldi [contact], Valérie Gouranton [contact], Thomas Lopez.

SIFORAS (Simulation for training and assistance) is a 3-year project (2011-2014) funded by the competitive cluster "Images et Réseaux". SIFORAS involves 4 academic partners (INSA Rennes, ENIB, CEA-List, ENISE) and 9 Industrial partners (Nexter Training, Delta CAD, Virtualys, DAF Conseils, Nexter Systems, DCNS, Renault, SNCF, Alstom). This project consists in developing a pedagogical system for technical training in industrial procedures. It aims at proposing Instructional Systems Design to answer the new objectives of training (Intelligent Tutorial System, mobility, augmented reality, high productivity). The Hybrid implication in the project shares some common means and goals with the Corvette project, in particular concerning its global architecture based on STORM and LORA models, and exploiting GVT software (section 5.2).

### 8.2.7. FUI Previz

**Participants:** Bruno Arnaldi [contact], Valérie Gouranton [contact].

Previz is a 3-year project (2013-2016) funded by the competitive cluster "Images et Réseaux". Previz involves 4 Academic partners (Hybrid/INSA Rennes, ENS Louis-Lumière, LIRIS, Gipsa-Lab) and 9 Industrial partners (Technicolor, Ubisoft, SolidAnim, loumasystem, Polymorph). Previz aims at proposing new previsualization tools for movie directors. The goal of Hybrid in Previz is to introduce new interactions between real and virtual actors so that the actor's actions, no matter his/her real or virtual nature, impact both the real and the virtual environment. The project will end up with a new production pipeline in order to automatically adapt and synchronize the visual effects (VFX), in space and time, to the real performance of an actor.

### 8.2.8. ADT MAN-IP

**Participant:** Valérie Gouranton [contact].

The ADT MAN-IP is a 2-year project (2013-2015) funded by Inria for software support and development. MAN-IP involves two Inria teams: Hybrid and MimeTIC. MAN-IP aims at proposing a common software pipeline for both teams to facilitate the production of populated virtual environments. The resulting software should include functionalities for motion capture, automatic aquisition and modification, and high-level authoring tools.

### 8.2.9. ADT OpenViBE-NT

**Participants:** Anatole Lécuyer [contact], Jussi Lindgren [contact], Jozef Legény.

The ADT OpenViBE-NT is a 2-year project (2012-2014) funded by Inria for support and development of the OpenViBE software (section 5.1). OpenViBE-NT involves four Inria teams: Hybrid, Potioc, Athena, Neurosys - all being extensive users of OpenViBE. OpenViBE-NT aims at improving the current functionalities of OpenViBE platform, and helping in supporting its active and ever growing community of users.

## 8.3. European Initiatives

### 8.3.1. FP7 VISIONAIR

**Participants:** Valérie Gouranton, Thierry Duval, Bruno Arnaldi.

- Program: FP7-INFRA
- Project acronym: VISIONAIR
- Project title: VISION Advanced Infrastructure for Research
- Duration: Feb 2011 - Feb 2015
- Coordinator: INPG
- Other partners: INPG France, University Patras Greece, Cranfield University United Kingdom, Universiteit Twente Netherlands, Universitaet Stuttgart Germany, ICBPP Poland, Univ. Méditerranée France, CNR Italy, Inria France, KTH Sweden, Technion Israel, RWTH Germany, PUT Poland, AMPT France, TUK Germany, University Salford United Kingdom, Fraunhofer Germany, I2CAT Spain, University Essex United Kingdom, MTASEAKI Hungary, ECN France, UCL United Kingdom, Polimi Italy, European Manufacturing and Innovation Research Association
- Abstract: Visionair calls for the creation of a European infrastructure for high level visualisation facilities that are open to research communities across Europe and around the world. By integrating existing facilities, Visionair aims to create a world-class research infrastructure for conducting state-of-the-art research in visualisation, thus significantly enhancing the attractiveness and visibility of the European Research Area. Hybrid team is mainly involved in Work Package 9 (Advanced methods for interaction and collaboration) led and supervised by Prof. Georges Dumont (MimeTIC Inria team).

## 8.4. International Initiatives

### *8.4.1. Associate Team SIMS*

**Participant:** Maud Marchal [contact].

SIMS is an Inria Associate Team involving Mimetic and Hybrid Inria teams in Rennes and the GAMMA Research Group of the University of North Carolina in the United States. SIMS focuses on realistic and effective simulation of highly complex systems based on human movement and interaction. The Associate Team has three main axes of research: crowd simulation, movement planning for autonomous virtual humans and real-time physical simulation for interactive environments. The latter axis is supervised by Maud Marchal. In this context, one Master student spent 8 months in the GAMMA Research Group, starting in November 2013.

## 8.5. International Research Visitors

### *8.5.1. Visits of International Scientists*

- Dr. Francesco Grani, Postdoc at the Aalborg University, Denmark, spent a half month stay in our group in Rennes in June 2013 to work on auditory feedback in virtual environments, in the frame of EU FP7 "VISIONAIR" project.

### *8.5.2. Internships*

- Mr. Takuya Sato, Master Student at the University of Tohoku in Sendai, Japan, spent a two-month internship in our group in Rennes in November and December 2013 to work on haptic feedback in collaborative virtual environments (Supervisors : Thierry Duval and Anatole Lécuyer).

### *8.5.3. Visits to International Teams*

- Mr. Anthony Talvas, PhD student in the team, spent a three-month stay at University Rey Juan Carlos in Madrid, Spain, under the supervision of Pr. Miguel Otaduy. His stay was funded by Rennes Metropole.

# 9. Dissemination

## 9.1. Scientific Animation

### *9.1.1. Editorial boards of journals*

- Anatole Lécuyer is associate editor of ACM Transactions on Applied Perception (ACM TAP), and International Journal on Human-Computer Studies (IJHCS) .
- Maud Marchal is associate editor of Computer Graphics Forum (CGF).

### *9.1.2. Technical program committees of conferences*

- Anatole Lécuyer was program and conference chair of IEEE 3DUI'13. He was also in international program committees of: IEEE VR'13, Eurographics'13, ACM Siggraph Asia'13.
- Bruno Arnaldi was program chair of AFRV'13 and member of the international program committee of IEEE VR'13.
- Thierry Duval was in international program committees of: IEEE 3DUI'13, GRAPP'13, JVRC'13, IHM'13 (Demo co-chair), IEEE CogInfoCom'13, ACM VRST'13, VRIC'13.
- Valérie Gouranton was in international program committee and Chair of Symposium "VR-Serious Game and Interactive Storytelling" at VRIC'13.
- Maud Marchal was in international program committees of: IEEE 3DUI'13, Eurographics Short Papers'13, GRAPP'13.

- Ferran Argelaguet was in international program committees of: IEEE 3DUI'13, ACM VRST'13, ICAT'13 (Demo co-chair), ACM SUI'13.

### 9.1.3. Selection committees

- Anatole Lécuyer was in the selection committee for an Associate Professor position at "Université de Bordeaux 1".
- Bruno Arnaldi was in the selection committee for a Professor position at "Ecole Normale Supérieure de Cachan Antenne de Bretagne" and for a Professor Position at "INSA de Rennes".
- Thierry Duval was in the selection committee for an Associate Professor position at "École Nationale d'Ingénieurs de Brest".

### 9.1.4. Participation in seminars, invitations

- Anatole Lécuyer has been invited to give a keynote talk at AFIHM'13 (Bordeaux), and other talks at: SOFMER'13 (Reims), Chimie et TIC'13 (Paris). He has participated in "Dagstuhl Seminar 13241" on "Virtual Realities" at Schloss Dagstuhl (9–14 June 2013, Germany).

### 9.1.5. Animation at the international level

- Anatole Lécuyer was co-organizer of a Course on "Walking in Virtual environments" at ACM CHI'13 (with F. Steinicke, Y. Visell and J. Campos), a Tutorial on "BCI and Haptics" at World-Haptics'13 (with M. Ziat), a Workshop on "BCI Feedback" at the BCI Meeting'13 (with F. Lotte, and R. Scherer), a Workshop on "BCI and EEG" at Rennes Hospital (with I. Bonan, and G.TEC Company). He was also reviewer for conferences: JVRC'13, VRIC'13.
- Bruno Arnaldi was reviewer for conference IEEE VR'13 and reviewer for an ERC Advanced Grant Proposal.
- Thierry Duval was reviewer for international journal IEEE THMS, and for conferences: VRIC'13, IEEE 3DUI'13, IHM'13, JVRC'13, ACM VRST'13, IEEE VR'13, GRAPP'13. He also served as an expert for evaluation of the European FP7 project "Beaming".
- Valérie Gouranton was reviewer for international journal "Journal on Computing and Cultural Heritage", and for conference VRIC'13.
- Maud Marchal was reviewer for international journals: IEEE TVCG, IEEE ToH, and for conferences: IEEE VR'13, IEEE 3DUI'13, Eurographics'13, Siggraph'13, MICCAI'13, IEEE EMBS'13.
- Ferran Argelaguet was a reviewer for international journals: IEEE Computer Graphics and Applications, ACM Journal on Computing and Cultural Heritage, and for conference JVRC'13.

### 9.1.6. Animation at the national level

- Anatole Lécuyer was member of executive committee of the French Association for Virtual Reality (AFRV) until October 2013.
- Bruno Arnaldi was vice-president and member of the executive committee of AFRV.
- Thierry Duval was a member of AFRV and AFIHM. He served as an expert for selection of french ANR projects.
- Valérie Gouranton was member of executive committee of AFRV since October 2013.

### 9.1.7. Animation at the regional and local level

- Bruno Arnaldi was vice-president of the scientific committee of "INSA de Rennes" and was in the CSV (selection committee) of Competitivity Cluster "Images et Réseaux".
- Valérie Gouranton was co-head of a Master 2 in Computer Science (joint to University of Rennes 1, INSA Rennes, ENS CACHAN Antenne Bretagne, Supelec, UBO, ENIB, ENSTA Bretagne, Télécom Bretagne, UBS). She was also member of the scientific committee of INSA Rennes and member of the laboratory committee of IRISA.

## 9.2. Teaching - Supervision - Juries

### *9.2.1. Teaching*

Anatole Lécuyer:

Master MNRV: "Haptic Interaction", 9h, M2, ENSAM, Laval, FR

Master SIBM: "Haptic and Brain-Computer Interfaces", 4,5h, M2, University of Rennes 1, FR

Bruno Arnaldi:

Master INSA Rennes: "VAR: Virtual and Augmented Reality", 12h, M2, INSA Rennes, FR

Master INSA Rennes: "Virtual Reality", 6h, M2, INSA Rennes, FR

Master INSA Rennes: Projects on "Virtual Reality", 20h, M1, INSA Rennes, FR

Thierry Duval:

Master STS Informatique: "HCI", 54h, M1, ISTIC, University of Rennes 1, FR

Master STS Informatique: "Introduction to Virtual Reality", 24h, M1, ISTIC, University of Rennes 1, FR

Master STS Informatique: "Software engineering for HCI", 15h, M1, ESIR, University of Rennes 1, FR

Master STS Informatique GL and MITIC: "Software engineering for HCI", 37h, M2, ISTIC, University of Rennes 1, FR

Master STS Informatique GL and MITIC: "Collaborative Virtual Environments", 38h, M2, ISTIC, University of Rennes 1, FR

Valérie Gouranton:

Licence: "Introduction to Virtual Reality", 12h, L2 and responsible of this lecture, INSA Rennes, FR

Licence: Project on "Virtual Reality", 13h, L3 and responsible of this lecture, INSA Rennes, FR

Master INSA Rennes: "Virtual Reality", 12h, M2, INSA Rennes, FR

Master INSA Rennes: Projects on "Virtual Reality", 20h, M1, INSA Rennes, FR

Maud Marchal:

Master INSA Rennes: "Modeling and Engineering for Biology and Health Applications", 48h, M2 and responsible of this lecture, INSA Rennes, FR

Master SIBM: "Biomedical simulation", 3h, M2, University of Rennes 1, FR

### *9.2.2. Supervision*

PhD in progress: Jérémy Lacoche, "Plasticity for user interfaces in mixed reality", Started in September 2013 at B<>COM Research Institute, Supervised by T. Duval, B. Arnaldi, É. Maisel and J. Royan

PhD in progress: Morgan Le Chénéchal, "Activity and perception for distant collaboration in virtual environments", Started in September 2013 at B<>COM Research Institute, Supervised by B. Arnaldi, T. Duval, V. Gouranton and J. Royan

PhD in progress: Lucas Royer, "Visualization tools for needle insertion in interventional radiology", Started in September 2013 at B<>COM Research Institute, Supervised by A. Krupa, M. Marchal and G. Dardenne

PhD in progress: Andéol Evain, "BCI-based Interaction", Started in September 2013, Supervised by N. Roussel, G. Casiez, F. Argelaguet and A. Lécuyer

PhD in progress: Guillaume Claude, "Synthesis and Simulation of Process Models ", Started in September 2013, Supervised by V. Gouranton and B. Arnaldi

PhD in progress: François Lehericey, "Collision Detection HPC", Started in October 2013, Supervised by V. Gouranton and B. Arnaldi

PhD in progress: Merwan Achibet, "Dexterous manipulation in virtual environments", Started in November 2012, Supervised by A. Lécuyer and M. Marchal.

PhD in progress: Jonathan Mercier-Ganady, "Hybrid Brain-Computer Interfaces", Started in October 2012, Supervised by M. Marchal and A. Lécuyer

PhD in progress: A. Talvas, "Bimanual haptic manipulation", Started in October 2011, Supervised by A. Lécuyer and M. Marchal.

PhD in progress: Thi Thuong Huyen Nguyen, "New 3D techniques for collaborative interaction and navigation that preserve users' immersion", Started in October 2011, Supervised by T. Duval

PhD in progress: Jérôme Ardouin, "Display of wide field-of-views in real and virtual environments", Started in January 2011, Supervised by M. Marchal, E. Marchand and A. Lécuyer

PhD in progress: Fabien Danieau, "Haptic Movies", Started in October 2010, Supervised by M. Christie, P. Guillotel, J. Fleureau and A. Lécuyer

### *9.2.3. Juries*

- Anatole Lécuyer: Mehdi Ammi (HDR, Examiner, University of Paris XI-Orsay), Jérémy Laviole (PhD, Referee, University of Bordeaux 1), Yuan Yang (PhD, Examiner, ENSTA-Télécom Paris Tech, Paris).
- Bruno Arnaldi: Jean-Marc Cieutat (HDR, Estia Biarritz), Nicolas Courty (HDR, UBS Vannes), Jonathan Wonner (PhD, University of Strasbourg), Jonathan Perrinet (PhD, University of Rennes 1).

## 9.3. Popularization

- Massive media coverage of the results of OpenViBE2 project (section 8.2.5) : following a press conference and press release organized in January 2013. This ended up with numerous appearances in the media (TV, Press, Radio).
- "Journées Nationales d'Archéologie" 2013 : organization and numerous demos of immersive and VR results of our team in Immersia room, Rennes, June 2013 [34].
- "Festival de la Science" 2013 : booth and demo of the FLyVIZ system, in Betton, October 2013.
- "Nuit de la Science" 2013 : demos of FLyVIZ system and Corvette project, Rennes, October 2013.
- "Colloque Chimie et TIC 2013" : presentation "Interagir par la pensée avec les Interfaces Cerveau-Ordinateur" (A. Lécuyer), Maison de la Chimie, Paris, October 2013.
- "Journées Science et Musique" 2013 : organization of this event, and presentation of several demos of the team in Immersia room, Rennes, October 2013.

# 10. Bibliography

## Major publications by the team in recent years

[1] J. ARDOUIN, A. LÉCUYER, M. MARCHAL, C. RIANT, E. MARCHAND. *"FlyVIZ": A Novel Display Device to Provide Humans with 360o Vision by Coupling Catadioptric Camera with HMD*, in "ACM Symp. on Virtual Reality Software and Technology, VRST'12", 2012, http://hal.inria.fr/hal-00750613

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F. ARGELAGUET SANZ, D. A. GÓMEZ JÁUREGUI, M. MARCHAL, A. LÉCUYER. *Elastic Images: Perceiving Local Elasticity of Images Through a Novel Pseudo-Haptic Deformation Effect*, in "ACM Transactions on Applied Perception", August 2013, vol. 10, n° 3, pp. 17:1–17:14, http://hal.inria.fr/hal-00907775.

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