INRIA

Project-Team bunraku

Perception, decision and action of real and virtual humans in virtual environments and impact on real environments

Rennes - Bretagne-Atlantique

Theme : Interaction and Visualization

Activity Report

2010

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2. Overall Objectives

2.1. Introduction

The synthetic definition of the research area of the Bunraku Project is: *Perception, decision and action of real and virtual humans in virtual environments and impact on real environments*. The main objective of the Bunraku project is to develop cross fertilization of researches in the fields of virtual reality and virtual human. Our challenge is to allow real and virtual humans to naturally interact in a shared virtual environment. This objective is very ambitious as it requires developing and federating several research fields. However, it is fundamental for several areas such as taking into account the human activity in manufacturing, the individual or collective training process, or the human study in cognitive sciences. We have the chance in the team to gather competencies in complementary research areas that allow us to address most of the problems to be solved. Concerning other domains, we are developing strong collaborations with well known research labs in their respective fields.

One of the main concerns of virtual reality is how real users can interact with objects of the virtual world. More generally, interaction can be the result of an individual interaction of one user with one object, but also a resulting interaction between objects in a chain reaction, a common interaction of several users on the same object, and can also be between real and virtual humans. User interaction with objects of the world should be both physical and cognitive: body and brain should be both part of the interaction by the concurrent use of gestures, haptic, gaze, and speech. To allow this multimodal interaction with objects within the world, we will have to develop a generic multilevel model of the objects of the world, and corresponding multimodal rendering (visual, haptic, audio, cognitive) and acting (language, gesture, mind).

Another key objective of Bunraku concerns the interaction between real and virtual humans with the objective to allow them to cooperate and communicate together, but also to be interchanged in a dedicated applicative context. To reach this ambitious objective, we have to develop expressive autonomous human-like characters able to perform in real-time complex and believable actions. Concerning the motion control of virtual humans, we have to increase the introduction of dynamic laws and physical capabilities inside our models to produce more complex and credible motions. In the same time, we have also to take into account two very significant constraints: real-time and controllability. Concerning multi-modal rendering, we have to develop a solution to synchronize in a reactive way gestures of a virtual human with other modalities such as speech (co-verbal gestures) and gaze, in a non predictive context.

To combine autonomy and believability, we are also working on a unified architecture to model individual and collective human behaviors. This architecture includes reactive, cognitive, rational and social skills and manage individual and collective behaviors. To tackle the embodiment of cognitive symbols we have to develop a complex hierarchy of perception decision action loops, by managing the bidirectional exchanges of information between the different levels. We are also continuing to develop our model of behavior coordination, by integrating it in an audio-visual attentive coordination, integrating the management of human memory, the filtering of attention and the cognitive load.

Moreover, to study the real human activity or to train them in the context of a virtual reality application, it is important to control the evolution of the virtual world and in particular the activity of the autonomous characters: this is the purpose of the scenario to supervise this evolution. Orchestrating an interactive session is useful to take partially the control of autonomous characters populating the virtual world, but also to control the impact of the user interaction.

Our objectives are decomposed into three complementary research themes:

- Multimodal interaction with objects within the world;
- Expressive autonomous characters;
- Interactive scenario languages.

To reach all these objectives, it is necessary to develop complementary research activities. In the past years, we have worked independently on most of these topics. In the Bunraku research group, in complement of the individual evolution of the research activity on each field, we want to reach a new stage concerning their integration into a common and federative research program.

2.2. Highlights

2.2.1. SIGGRAPH Paper on Crowd Simulation

Members of the Bunraku team have published new results on Crowd Simulation at the SIGGRAPH conference [15]. The proposed approach relies on the simulation of optic flow of the perceived environment to achieve collision-free navigation. Several examples of our simulation results demonstrates that the emergence of self-organized patterns of walkers is reinforced using this approach.

2.2.2. Best presentation award at ICAT 2010

Quentin Avril, PhD student in the Bunraku team, obtained the best presentation award for his paper entitled "Synchronization-Free Parallel Collision Detection Pipeline" [30], presented at the ICAT conference.

2.2.3. OpenVibe exhibition at the Museum of Science and Industry of La Villette

Since April 2010, the Museum of Science and Industry of La Villette in Paris is hosting the Tech 'Gallery: an exhibition dedicated to the technologies of tomorrow. In association with the laboratory Lutin Userlab and the EEG manufacturer g.tec, we present OpenViBE and the "Use-The-Force" demonstrator in this exhibition.

2.2.4. A new Virtual Reality room

The team was the first in France to host a large-scale immersive virtual reality equipment known as Immersia. This year, our virtual reality room is renewed. It will be composed of a new wall with four faces (front, two sides and ground), an ART tracker to track user position and a Yamaha sound rendering system linked to Genelec speakers with 10.2 format sound controlled by the user position. This new equipement allowed us to become a key partner of the VISIONNAIR european project which aims at creating a European infrastructure that should be a unique, visible and attractive entry towards high level visualisation facilities.

3. Scientific Foundations

3.1. Panorama

Virtual Reality is a scientific and technological domain exploiting computer science and sensory-motor devices in order to simulate in a virtual world the behavior of 3D entities in real time interaction with themselves and with one or more users in pseudo-natural immersion using multiple sensory channels. Virtual Reality can be defined as a set of dedicated hardware and software techniques that allow one or several users to interact in a natural way with numerical data sensed by the way of sensory channels.

During last years, our main research activity has been concerned with real-time simulation of complex dynamic systems, and we were also interested in investigating real-time interaction between these systems and the user(s). Our research topics addressed mechanical simulation, lighting simulation, control of dynamic systems, behavioral simulation, real-time simulation, haptic and multimodal interaction, collaborative interaction and modeling of virtual environments.

3.2. Dynamic models of motion

Glossary

Animation: Models and algorithms that produce motion accordingly to the animator specification.

Physically Based Animation: Animation models which take into account the physical laws in order to produce motion

Hybrid System: dynamic system resulting of the composition of a part which is differential and continuous and a part which is a discrete event system.

State Vector: data vector representing the system at time t, for example: position and velocity.

The use of 3D objects and virtual humans inside a virtual environment imply to implement dedicated dynamic models. However, the desired interactivity induces the ability to compute the model in real-time. The mathematical model of the motion equations and its corresponding algorithmic implementation are based on the theory of dynamic systems and uses tools from mechanics. The general formulation of these equations is a non-linear second order (in time) differential system coupled with algebraic equations (DAE: Differential Algebraic Equation) defined by:

$$\underline{\underline{M}}(\overrightarrow{q})\,\overrightarrow{\ddot{q}} \;=\; \overrightarrow{N}(\overrightarrow{q},\,\overrightarrow{\dot{q}},t) \tag{1}$$

where $\underline{\underline{M}}$ is the mass matrix, $\overrightarrow{N}(\overrightarrow{q},\dot{q},t)$ are the actions and non-linear effect (Coriolis) and $\overrightarrow{q}$ are the output parameters describing the system. In case $\overrightarrow{q}$ are known and $\overrightarrow{N}$ is unknown, inverse dynamic approaches are mandatory to solve the problem. If we concentrate on deformable objects, the equation becomes a second order (in time) and first order (in space) differential system defined point wise on the domain D occupied by the object:

$$div\underline{\sigma}(\overrightarrow{x}(t)) + \rho(\overrightarrow{f_d} - \frac{d^2\overrightarrow{x}(t)}{dt^2}) = \overrightarrow{0} \tag{2}$$

where $\overrightarrow{x}(t)$ stands for the current position, $\underline{\sigma}$ is the stress tensor in the material and is related to the deformation tensor $\underline{\varepsilon}$ by the relation $\underline{\sigma} = \underline{\underline{A}}\,\underline{\varepsilon}$ ($\underline{\underline{A}}$ is the constitutive material law tensor), ρ is the specific mass and $\overrightarrow{f_d}$ is a given force by volume unit (say gravity). These equations have to be solved by approximation methods (Finite Element Method: FEM) which may be difficult in real time. When contact or collisions occur, they lead to discontinuities in the motion. To solve the above DAE system, we prefer to use a discontinuous formulation expressed in terms of measure that is issued from Non-Smooth Contact Dynamics (NCSD) $\underline{M}(\overrightarrow{q})d\overline{q} = \overrightarrow{N}(\overrightarrow{q},\overline{q},t)dt + \overrightarrow{R}dv$ where $\overrightarrow{R}$ is the density of the contact impulsion. As a collision involves a local deformation of the contacting objects, another choice is to consider the deformation $\underline{\varepsilon}$ of the object. This resolution is expected to be more precise but also to violate the real time constraint.

For motion control, the structure of the dynamic model of the motion becomes a hybrid one, where two parts interact. The first one is the above-mentioned differential part while the second one is a discrete event system:

$$\frac{d\overrightarrow{q}}{dt} = \dot{\overrightarrow{q}} = \overrightarrow{f}(\overrightarrow{q}(t), \overrightarrow{u}(t), t)$$
$$\overrightarrow{q}_{n+1} = \overrightarrow{g}(\overrightarrow{q}_n, \overrightarrow{u}_n, n) \tag{3}$$

In this equation, the state vector $\overrightarrow{q}$ is related to the command vector $\overrightarrow{u}$.

3.3. 3D interaction

Glossary

Interaction: the location of two people in the same place, if they are conscious of this, induces an interaction between them. An interaction consists in the opening of a loop of data flow transmission channels between them making sense on each of them and modifying their own cognitive state.

3D interaction is an important factor to improve the feeling of immersion and presence in virtual reality. However, the introduction of a third dimension when interacting with a virtual environment makes inappropriate most of the classical techniques used successfully in the field of 2D interaction with desktop computers up to now. Thus, it becomes necessary to design and evaluate new paradigms specifically oriented towards interaction within 3D virtual environments.

Two components are classically isolated when considering 3D user interfaces and 3D interaction:

1. the interaction device, which sends the intentions of the user to the virtual environment (input device) and/or feeds back some information to him/her (output device);

2. the interaction technique, which corresponds to the "interpretation" of the information received or sent to the user by the system, i.e. the scenario of use of the interaction device when considering a specific task to be achieved in the virtual environment.

The design of 3D interaction techniques is conceived as an iterative process of *design-evaluation-redesign* which ends when the technique reaches its criteria of use. Another objective of the evaluation of the 3D interaction technique is to determine the model of performance, i.e. the prediction of the performance of the user given a certain task and a certain 3D interaction technique. The most famous example is probably the Fitt's law (Equation 4) which predicts the time (T) spent to reach a target with a given width (W) and located at a given distance (D). In this equation, the constant a and b are determined empirically according to the pointing task and the interaction device used.

$$T = a + b.\log_2\left(\frac{D}{W} + 1\right) \qquad (4)$$

The methods used to evaluate the 3D interfaces correspond to the standards defined in the field of 2D Human-Computer Interaction. We can distinguish the *comparative evaluation* which compares the performances of several techniques on the same task. Then the *heuristic evaluation* relies on the knowledge of a group of experts, who assess the efficiency of the technique, taking into account the standards and the design rules of their area. Other techniques like *questionnaire* and *interviews* are often used as a complement of the previous methods. Several questionnaires have been set up for instance to address the subjective feeling of *presence* in virtual environments.

3.4. Visual rendering

Glossary

Global illumination :   direct and indirect illumination computation.
Rendering: computation of an image of a virtual world as seen from a camera.
Partitioning :   subdivision of a 3D model into cells.
Client-server :   a server contains complex 3D scenes, a client sends requests for objects to the server.
GPU :   Graphics Processing Unit.

High fidelity rendering requires the use of a global illumination model that describes the light transport mechanism between surfaces, that is, the way every surface interacts with the others. Therefore, the global illumination model is a key problem when accuracy is needed in the rendering process (photorealism or photo-simulation) and is no more than an integral equation to be solved:

$$L(x \to \Theta) = L_e(x \to \Theta) + \int_{\Omega_x} f_r(x, \Psi \longleftrightarrow \Theta).L(x \longleftarrow \Psi).\cos(\Psi, n_x).d\omega_\Psi \qquad (5)$$

where $L()$ is the radiance, n_x is the normal of the surface at location x, L_e the self-emitted radiance, x a point on a surface, Ψ the incident direction, Θ the outgoing direction, and $d\omega$ the differential solid angle around the incident direction.

Computing global illumination amounts to solve this integral equation. Unfortunately, this is still a demanding process in terms of memory and computation resources. Our objective is to propose methods that would perform global illumination computation interactively and in real-time. Our methods rely on the radiance caching mechanism and exploit the performances of the new graphics cards (GPU) even in case of complex scenes. We are also interested in subsurface scattering (for modeling and rendering translucent objects such as human faces) and in the modeling and rendering in real-time of large natural scenes.

3.5. Virtual humans

Glossary

Avatar: it is the representation of the user in the virtual world. This representation can be either anthropomorphic or metaphoric.
Autonomous Agent: An autonomous agent is a virtual human situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future.

Human motion is a very challenging field because it is the result of numerous complex processes partially studied in biomechanics, neuroscience or physiology. One of the main outcomes is to understand the laws that capture the naturalness of human motion: what is the role of physical laws and of neurological and physiological processes? For example, neuroscientists studied single arm reaching tasks and suggested that the central nervous system uses an optimality criterion called "minimum Jerk" to calculate the trajectory along which to move:

$$min \sum_{i=1}^{n} \left(\frac{d^3}{dt^3}.\theta_i \right)^2 \qquad (6)$$

where n is the number of degrees of freedom and θ_i is the ith degree of freedom. In addition to general mechanical laws, many other criteria were proposed in the literature but they are all subject to controversy because they are linked to dedicated protocols that are far from real natural behaviors. Coupling motion analysis and simulation is a promising issue for understanding the subtle relations between all the parameters and laws involved in natural motion control. In computer animation, inverse kinematics is often used to calculate the relations between angular trajectories and Cartesian constraints (such as commanding the position of a given point of the skeleton, including the character's center of mass):

$$\Delta\theta = J^+(\theta)\Delta X - \alpha(I - J^+ J)z \qquad (7)$$

where J is the Jacobian of the kinematic function returning the position of the task X according to the angles θ, α is a weight, I is the identity matrix and z is called secondary task. This secondary task can embed the laws suggested in human movement sciences and allows evaluating their effect on the resulting calculated motion. Synthesizing a controller for a human-like dynamic system could also be considered as inverting the function linking the forces and the motion while minimizing a set of criteria intrinsically dealing with generic mechanical laws.

Modeling the human behavior requests to take into account a certain number of topics such as understanding mechanisms underlying functions such as natural language production and perception, memory activity, multi-sensory perception, muscular control and last but not least the production of emotions.

Our problem is not to reproduce the human intelligence but to propose an architecture making it possible to model credible behaviors of anthropomorphic virtual actors evolving/moving in real time in virtual worlds. The latter can represent particular situations studied by psychologists of the behavior or to correspond to an imaginary universe described by a scenario writer. The proposed architecture should mimic all the human intellectual and physical functions.

3.6. Interactive Scenario Languages

To study the real human activity or to train them in the context of a virtual reality application, it is important to control the evolution of the virtual world and in particular the activity of the autonomous characters: this is the purpose of the scenario to supervise this evolution. Scenarizing an interactive session is useful to take partially the control of autonomous characters populating the virtual world, but also to control the impact of the user interaction. For example, it is useful to create situations that can be both reproduced for each user and adapted to its own interactive capabilities. Thus, the orchestration of a virtual world requires to propose a solution to combine interactivity and narrativity. To propose a generic scenario language, we have to formalize the different natures of interaction. This is the first step towards the development of high level scenario languages. As some VR applications require also to make interoperate several software components executed on an heterogenous network of computers, it is also necessary to manage at a high level the protocol of dialog between them, including the different natures of interaction.

4. Application Domains

4.1. Panorama

The research topics of the Bunraku team are strongly related to a broad range of application domains. Figure 1 presents some of the topics we explore. Hereinafter we describe three of them – namely industry, sports and entertainment.
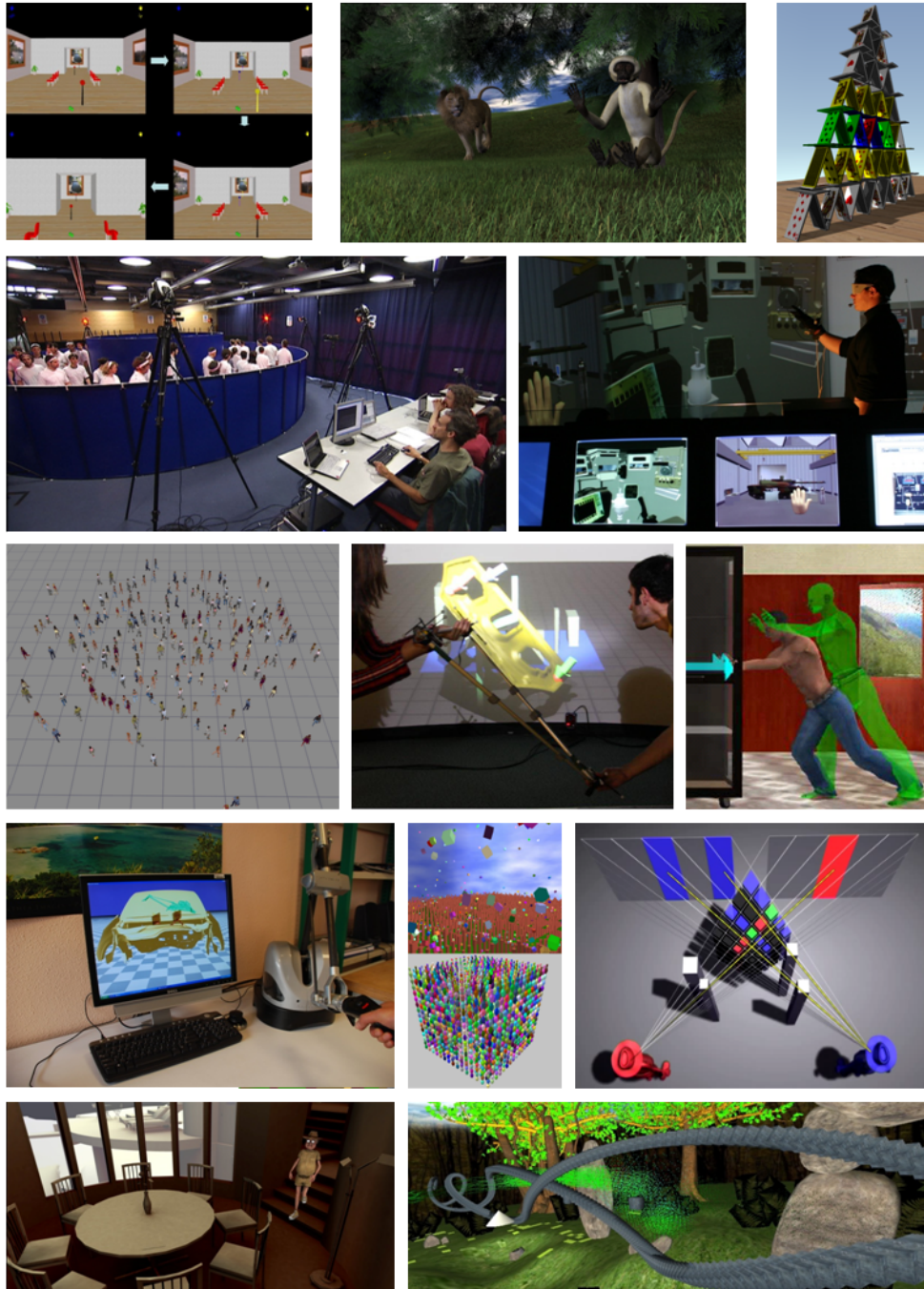
Figure 1. Illustration of research topics and applications in the Bunraku team.

4.2. Industrial products and process

The applications to the industrial domain are very promising. For instance, the PSA Automotive Design Network, which is a new design center, groups all the tools used for automotive design, from classical CAD systems to Virtual Reality applications. Renault has also conducted research to couple the virtual assembling methods into CAD systems. The coupling of virtual reality and simulation algorithms is a key point. Other major issues in which industrials are strongly involved are (i) populating and simulating complex human activities in large-scaled industrial plants (Digital Plant 1 & 2 Projects of the competitiveness cluster System@tic), (ii) focussing on collaborative tasks between multiple users in digital mockups and for scientific visualization (ANR Part@ge and ANR Collaviz) and finally (iii) tackling the challenging problem of training in Virtual Reality by providing interactive scenario languages with realists actions and reactions within the environment (GVT Project and Grant).

4.3. Narrative and interactive virtual worlds

Contemporary artistic creation nourishes more and more of the use of new technologies and we attend at the same time a decompartmentalization of the classic arts. The analysis of recent creations in the field of interactive pluri-artistic pieces put to evidence the difficulties encountered by artists and the existing lacks in terms of software components and technologies. Our objective is to propose a unified but generic paradigm for describing interactive art pieces in order to be able to simplify the work of the authors, and process part of the work automatically, so that no only the authors can concretise their ideas in their favourite software, but communication between environments can be taken in charge automatically by the system. We intend to model and develop a new meta-language allowing a high level communication between different softwares implied in the creation and execution of interactive artistic installations.

4.4. Sports and health care

Works dealing with human motion simulation are very interesting for sports scientists and for doctors in handicapped people rehabilitation. In sports, simulation is an alternative to statistical analysis in order to identify the parameters lined to performance. Moreover simulation could also provide new training environments involving virtual reality. The problem here is to provide complementary tools to coaches in order to train specific capacities. We extend the study of duels between the real goal-keeper and the virtual fighter in a hand-ball game by integrating glance tracking using an oculometer and a followup of the orientation of the head. We use the real-time functionalities of our new motion capture system to allow the virtual fighter to adapt its behaviors to the reactions of the goal-keeper. We now plan to study and model tactical problems in collective plays. This work is jointly undertaken with the Biomechanics team of M2S (joint lab between the University of Rennes 2 and ENS Cachan).

5. Software

5.1. Panorama

In order to validate our scientific results, we develop prototypic softwares with the capacity to treat industrial problems. The softwares presented in this section are all used in industrial cooperations.

5.2. MKM: Manageable Kinematic Motions

Participants: Richard Kulpa [contact], Bruno Arnaldi, Nicolas Chaverou, Franck Multon, Yann Pinczon du Sel.

We have developed a framework for animating human-like figures in real-time, based on captured motions. This work was carried-out in collaboration with the M2S Laboratory (Mouvement, Sport, Santé) of the University Rennes 2.

In this software, we propose a morphology-independent representation of the motion that is based on a simplified skeleton which normalizes the global postural information. This formalism is not linked to morphology and allows very fast motion retargetting and adaptation to geometric constraints that can change in real-time. This approach dramatically reduces the post production time and allows the animators to handle a general motion library instead of one library per avatar.

The framework provides an animation library which uses the motions either obtained from our off-line tool (that tranforms standard formats into our morphology-independent representation) or parameterized models in order to create complete animation in real-time. Several models are proposed such as grasping, orientation of the head toward a target. We have also included a new locomotion model that allows to control the character directly using a motion database.

In order to create realistic and smooth animations, MKM uses motion synchronization, blending and adaptation to skeletons and to external constraints. All those processes are performed in real-time in an environment that can change at any time, unpredictably.

All these features have been used to anticipate and control the placement of footprints depending on high level parameters. This link between control and behavior levels has been used with the TopoPlan software to have realistic motion adaptations in constrained environments during reactive navigation.

5.3. HPTS++: Hierarchical Parallel Transition System ++

Participants: Stéphane Donikian, Fabrice Lamarche [contact].

HPTS++ is a platform independent toolkit to describe and handle the execution of multi-agent systems. It provides a specific object oriented language encapsulating C++ code for interfacing facilities and a runtime kernel providing automatic synchronization and adaptation facilities.

The language provides functionalities to describe state machines (states and transitions) and to inform them with user specific C++ code to call at a given point during execution. This language is object oriented and supports concepts such as polymorphism and inheritance (state machines and user defined C++ classes). The compilation phase translates a state machine in a C++ class that can be compiled separately and linked through static or dynamic libraries. The runtime kernel includes a scheduler that handles parallel state machines execution and that provides synchronization facilities such as mutual exclusion on resources, dead lock avoidance, notions of priorities and execution adaptation in accordance with resources availability.

HPTS++ also provides a task model. Thanks to this model, the user can describe primitive behaviors through atomic tasks and combine them, thanks to some provided operators (sequence, parallelism, loops, alternatives). Theses operators are fully dynamic. Hence they can be used at runtime to rapidly create complex behaviors.

5.4. TopoPlan: Topological Planner and Behaviour Library

Participant: Fabrice Lamarche [contact].

TopoPlan (Topological Planner) is a toolkit dedicated to the analysis of a 3D environment geometry in order to generate suitable data structures for path finding and navigation. This toolkit provides a two step process: an off-line computation of spatial representation and a library providing on-line processes dedicated to path planning, environmental requests...

TopoPlan is based on an exact 3D spatial subdivision that accurately identifies floor and ceiling constraints for each point of the environment. Thanks to this spatial subdivision and some humanoid characteristics, an environment topology is computed. This topology accurately identifies navigable zones by connecting 3D cells of the spatial subdivision. Based on this topology several maps representing the environment are extracted. Those maps identify obstacle and step borders as well as bottlenecks. TopoPlan also provides a runtime library enabling the on-line exploitation of the spatial representation. This library provides several algorithms including roadmap-based path-planning, trajectory optimization, footprint generation, reactive navigation and spatial requests through customizable spatial selectors.

TopoPlan behavior is a library built on top of TopoPlan and MKM providing several behaviors described thanks to the HPTS++ task model. Its goal is to provide a high level interface handling navigation and posture adaptation within TopoPlan environments. Provided behaviors include:

- A behavior handling fully planned navigation toward an arbitrary destination. This behavior precisely handles footprint generation within constrained environments such as stairs for instance.
- A behavior controlling an MKM humanoid to follow a trajectory specified by the user.
- A behavior controlling MKM to follow a list of footprints given by the user.
- A behavior adapting the humanoid posture to avoid collision with ceiling. This behavior runs in parallel of all other behaviors and adapts humanoid motion when needed without any user intervention.
- A behavior handling reactive navigation of virtual humans. This behavior plans a path to a given target and follows the path while avoiding collisions with other navigating entities.

Those behaviors have been built using the HPTS++ task model. Thus, they can be easily combined together or with other described behaviors through task operators.

5.5. GVT : Generic Virtual Training

Participants: Bruno Arnaldi [contact], Valérie Gouranton, Stéphanie Gerbaud, Andrés Saraos Luna.

The aim of GVT software is to offer personalized VR training sessions for industrial equipments. The most important features are the human and equipment security in the VR training (in opposition to the real training), the optimization of the learning process, the creation of dedicated scenarios, multiple hardware configurations: laptop computer, immersion room, distribution on network, etc.

The actual kernel of GVT platform is divided into two main elements that rely on innovative models we have proposed: LORA and STORM models.

- A Behavior Engine. The virtual world is composed of behavioural objects modelled with STORM (Simulation and Training Object-Relation Model).
- A Scenario Engine. This engine is used to determine the next steps of the procedure for a trainee, and its state evolves as the trainee achieves actions. The scenario is written in the LORA language (Language for Object-Relation Application).

A commercialized version of GVT, which includes a pedagogical engine developed in CERV laboratory, proposes training on individual procedures. A prototype is also available that enables users to train on collaborative procedures with one another or with virtual humans.

In the ANR Corvette 8.2.7, new features of GVT Software are proposed.

5.6. OpenViBE Software

Participants: Anatole Lécuyer [contact], Laurent Bonnet, Jozef Legény, Yann Renard, Aurélien Van Langhenhove.

OpenViBE is a free and open-source software devoted to the design, test and use of **Brain-Computer Interfaces**.

The OpenViBE platform consists of a set of software modules that can be integrated easily and efficiently to design BCI applications. Key features of the platform 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 LGPL-V2 licence, and it was officially released in June 2009. Since then, the OpenViBE software has already been downloaded more than 300 time, and it is used by numerous entities worldwide.

Our first international tutorial about OpenViBE was held at the International BCI Meeting in June 2010 (Monterey, US), with around 30 participants.

More information, downloads, tutorials, documentation, videos are available on OpenViBE website : http://openvibe.inria.fr

5.7. OpenMASK: Open-Source platform for Virtual Reality

Participants: Alain Chauffaut [contact], Thierry Duval, Laurent Aguerreche, Florian Nouviale.

OPENMASK (Open Modular Animation and Simulation Kit) is a federative platform for research developments in the Bunraku team. Technology transfer is a significant goal of our team so this platform is available as OpenSource software (http://www.openmask.org).

OpenMASK is a C++ software platform for the development and execution of modular applications in the fields of animation, simulation and virtual reality. The main unit of modularity is the simulated object (OSO) which can be viewed as frequental or reactive motors. It can be used to describe the behavior or motion control of a virtual object as well as input devices control like haptic interfaces.

We provide Model Driven Tools to help building OpenMASK applications without tedious and repeated coding and to improve reusability. Within Eclipse environment we offer an editor and a C++ code generator to design and build objects classes. The current OpenMASK 4.2 release is now based on MPI for distribution service, Ogre3D for visualisation service. One can benefit of new interaction tools for local or remote collaborative applications.

6. New Results

6.1. Representations of objects in virtual worlds

6.1.1. *New trends in collision detection performance*

Participants: Valérie Gouranton [contact], Bruno Arnaldi, Quentin Avril.

Virtual reality applications become more and more sized and result for a real time interaction is no longer satisfying. Our goal is to propose new models and algorithms enable to detect and adapt collision detection computations on the run-time architecture. More precisely the focus is made on the mapping of collision detection algorithms on the hardware layer.

We proposed a first way to parallelize the well-known *Sweep and Prune* algorithm on a multi-core architecture [29]. We obtain a 5x-6x speed-up on octo-cores architecture. We defined a new model of a parallel collision pipeline in which the two phases are simultaneously executed in parallel, sharing their data with a new buffer structure [30].

6.1.2. *Modal analysis for haptic manipulation of deformable models*

Participants: Zhaoguang Wang, Georges Dumont.

Real-time interaction between designer and deformable mock-up in VR (Virtual Reality) environment is a natural and promising manner to evaluate designing feasibility. Our research focuses on deformation verification of polystyrene moulds through real time haptic interaction. In order to produce high fidelity physically based simulation, finite element method (FEM) was introduced, but latency issue is a problem for real time haptic applications. We propose a two-stage method extended from linear modal analysis. In our method, modal subspace is pre-computed offline, and real time deformation is obtained by superposition of the responses of certain modes that are chosen depending on interaction requirement. There are two features in our method. Firstly, we apply an adapted meshing technique in pre-computation process. This technique allows a switching between different modal subspaces, which correspond to different interaction regions. Secondly, we divide real time deformation computation into two separate modules by extracting a sub-matrix from pre-computed modal matrix. This work is presented in IDMME / Virtual Concept 2010 [62].

6.1.3. *Haptic interaction for assembly/disassembly tasks*

Participants: Loïc Tching, Georges Dumont [contact].

Within the industrial framework, applications that need haptic interfaces mainly consist in combining assembly and disassembly tasks to validate virtual prototypes or to train operators. To assist users in performing the assembly of CAD objects, we proposed that , in complex assembly simulation, the user can intuitively interact with the virtual CAD environment. It is then possible, by using virtual fixtures (abstract perceptual information added to the simulation), to assist the user while leaving him a partial control of his movements.

The virtual scene is decomposed in two areas [19]. The first area is related to exploration of the virtual environment. It is composed of zones where no assembly is planned and where the user gets a classical haptic control of the object . The second area is related to the assembly tasks. To apply the constraint based guidance in the functional area, we qualify the task and associate both mechanical linkage(s) and virtual fixture(s). To create the constraints, we use topological information of CAD objects to identify the assembly areas, and model the trajectory with mechanical linkages, when possible. This phase is carried out by pre- processing and placing constraints for each zone of interest. Once the constraints and their associated geometric guides are set-up, the simulation switches between two different modes of control [57] related to the two areas described above.

A prototype has been developed developed in collaboration with the CEA-LIST within the Part@ge ANR project and has been presented . In 2007, we began this Loïc Tching's PhD thesis, defended in february [5] granted by Haption SA (CIFRE contract).

6.1.4. *Biomechanics modelling and physical simulation*

Participants: Georges Dumont [contact], Maud Marchal [contact], Loeiz Glondu, Charles Potonnier, Loïc Tching.

6.1.4.1. *Comparison of Physical Models for Haptic Interactions*

Haptic rendering has opened a new range of virtual reality applications, enabling a human user to interact with a virtual world using the sense of touch. This kind of interaction enables to enhance applications such as computer-assisted design, where 3D manipulations are part of the system. However, building an application with an accurate haptic feedback is still challenging, especially for interactions between rigid bodies, where stiff contacts can only be displayed with a high simulation frequency. Thus, we proposed the possibilities of implementation of a modular haptic display system that relies on two main components: a physical simulation part and a haptic rendering part. For that purpose, we define a generic coupling approach that enables to perform haptic rendering using admittance haptic devices, through a scaling interface that cleanly separates the physical simulation and the haptic rendering system of units. Four physical simulation libraries are evaluated with respect to haptic rendering quality criteria, based on their behavior in four discriminant test cases. We showed that the proposed approach leads to a modular, generic and stable haptic application.

This work has been published in the ASME World Conference on Innovative Virtual Reality [43].

6.1.4.2. *Validation of Biomechanical Models*

The validation of biomechanical models is crucial, especially for medical applications. We proposed a method for the creation of an anatomically and mechanically realistic brain phantom from polyvinyl alcohol cryogel (PVA-C) for validation of image processing methods for segmentation, reconstruction, registration, and denoising. PVA-C is material widely used in medical imaging phantoms for its mechanical similarities to soft tissues. The phantom was cast in a mold designed using the left hemihere of the Colin27 brain dataset and contains deep sulci, a complete insular region, and an anatomically accurate left ventricle. Marker spheres and inflatable catheters were also implanted to enable good registration and simulate tissue deformation, respectively. The phantom was designed for triple modality imaging, giving good contrast images in computed tomography, ultrasound, and magnetic resonance imaging. Multimodal data acquired from this phantom are made freely available to the image processing community (http://pvabrain.inria.fr) and will aid in the validation and further development of medical image processing techniques.

This work has been published in the 13th International Conference on Medical Image Computing and Computer Assisted Intervention [32].

6.1.4.3. Muscle forces estimation from motion capture data

One of the major preoccupations in industry is the improvement of the working conditions. The goal of this study is to use motion capture data in order to obtain muscles forces involved in the human forearm and hand. The challenge is to estimate in real-time the muscle forces involved in several working tasks in order to analyze and diagnozes the working conditions. Major interrogations are related to the physical validity of the adapted motions and the correct use of the computed forces and torques for producing physically valid motions.

Our current method to estimate muscle forces follows a four-stepped process:

1. acquisition of real motion data when following a prescribed scenario. This will lead to obtain a test database for motions that may occur in a working situation;

2. proposition of a kinematical model of the forearm with a special focus on the elbow and the forearm. The real data will be mapped on this model to obtain the geometrical data related to the real human who has performed the prescribed task. This model is used to perform an inverse kinematics study to obtain the kinematical parameters related to this motion [54];

3. inverse dynamics study of the forearm that leads to the joint torques related to the motion. This is achieved by building a dynamical model. The mass and inertia parameters used for this point are obtained by methods based on the literature;

4. use of these preliminary results as an input to a muscular model allowing to access to the forces that are developed inside the muscles. The current method proceeds with an optimization under non-linear constraints algorithm. Antagonism between muscles is taken into account by adding an additionnal constraint that translates the physiology of the joints [16].

The main results are the realization and the validation of a co-contraction ratio that allows to take this phenomenon into account in the elbow flexion, the realization and the evaluation of a new muscle forces estimation method based on barycentric bilinear interpolation that allows to compute muscle forces in real-time [55]. At last the complete pipeline allows to perform a quantitative analysis of the elbow flexion motion.

This work has been realized during the Ph.D of Charles Pontonnier, defended the 12th November 2010 [4].

6.2. Multimodal interaction with objects in virtual worlds

6.2.1. *Brain-Computer Interfaces*

Participants: Anatole Lécuyer [contact], Bruno Arnaldi, Laurent George, Fabrice Lamarche, Yann Renard, Aurélien Van Langhenhove.

Brain-computer interfaces (BCI) are communication systems that enable to send commands to a computer using only the brain activity. Cerebral activity is generally sensed with electroencephalography (or EEG). We describe hereafter our recent results in the field of brain-computer interfaces and virtual environments: (1) Novel signal processing techniques for EEG-based Brain-Computer Interfaces, and (2) Design and study of Brain-Computer Interaction with real and virtual environments.

6.2.1.1. Novel signal processing techniques for EEG-based Brain-Computer Interfaces

A first part of the BCI research conducted in the team is dedicated to EEG signal processing and classification techniques applied to cerebral EEG data.

BCI research appears as a promising way to improve brain understanding. Unfortunately, current BCI generally behave as "black boxes", i.e., we cannot interpret what algorithms automatically learnt from EEG data. This has motivated the BCI community to stress the need for BCI signal processing and classification techniques from which we could gain insights about the brain dynamics.

In [65], we have thus proposed a novel method to design a *fully interpretable EEG-based BCI*. Our approach can explain what power in which brain regions and frequency bands corresponds to which mental state, using "if-then" rules expressed with simple words. Our method can be broken down into three steps: 1) feature extraction based on inverse solutions, 2) classiffication based on fuzzy inference systems and 3) interpretability improvement based on linguistic approximation.

Evaluations of our algorithm suggested that knowledge from the literature was actually reflected by the rules automatically extracted. They also suggested that being able to interpret the BCI may help improve it. Incidentally, this BCI also appeared to have high classiffication performances. Therefore, the proposed method appears as a useful tool to 1) verify what has been learnt by the BCI and 2) to display and discuss the knowledge automatically extracted by the BCI with non technical people, e.g., medical doctors. It might also prove useful to gain knowledge about the brain dynamics when used to analyze new neurophysiological signals.

This work has been presented at the International BCI Meeting [65].

We have also proposed a general framework for integrating and developing novel signal-processing schemes for BCI within our OpenViBE software platform. The OpenViBE software was published in the Presence journal [17].

6.2.1.2. Brain-Computer Interaction with real and virtual environments

A second part of our BCI research is dedicated to the improvement of BCI-based interaction with real and virtual environments.

We have first initiated research on **implicit interaction based on Brain-Computer Interfaces**. In [41], we have indeed surveyed existing and past research on "Passive BCI". A novel way of using BCI has indeed emerged, which proposes to use BCI in a less explicit way : the so-called "passive" BCI. Implicit BCI or passive BCI refers to BCI in which the user does not try to control his brain activity. Thus the brain activity is assimilated to an input and can be used to adapt the application to the user's mental state. In [41], we have first studied "implicit interaction" in general and recalled its main applications. Then, we have made a survey of existing and past research on brain-computer interfaces for implicit human-computer interaction. It seems that BCI can be used in many applications in an implicit way, such as for adaptive automation, affective computing, or for video games. In such applications, BCI based on implicit interaction was often reported to improve performance of either the system or the user, or to introduce novel capacities based on mental states. Second, it is well-known that current explicit interaction with 3D virtual environments with BCI remain relatively basic and do not always compensate for the small number of commands provided by the BCI system. For instance, navigation techniques proposed so far are mostly based on very low-level commands, with generally a direct association between mental states and turning left or right, or moving forwards in the VE. In [13] we could introduce the use of **high-level commands for Brain-Computer Interfaces** and 3D interaction with VE. High-level commands should provide a more flexible, convenient and efficient system to interact with VE. In such a system, most of the complex tasks would be carried out by the system whereas the user would only have to provide a few and very high-level commands to accomplish the desired tasks. We illustrate this approach with a novel interaction technique for exploring large VE by using a BCI, thanks to the use of high level commands [13]. In this approach, the user can select points of interest in the VE by using a binary tree selection mechanism. He/she is then automatically transported to the selected target.

As an evaluation, we studied the performances of 3 subjects who used our interaction technique to navigate from room to room in a virtual museum. Our results show that, on average, navigating from one room to another by using a high-level interaction technique is significantly more efficient, being almost twice as fast, as when using a low-level interaction technique.

This suggests that our whole system may be used to navigate and interact with virtual worlds more efficiently and with more degrees of freedom than current approaches. More details can be found in a paper published in Presence journal [13].

6.2.2. *Natural Interactive Walking in Virtual Environments*

Participants: Anatole Lécuyer [contact], Maud Marchal [contact], Bruno Arnaldi, Gabriel Cirio, Tony Regia Corte, Sébastien Hillaire, Léo Terziman.

We describe hereafter our recent results obtained in the field of "augmented" or "natural interactive" walking in virtual environments. Our first objective is to better understand the properties of human perception and human locomotion when walking in virtual worlds. Then, our intention is to improve the multisensory rendering of human locomotion and human walk in virtual environments, making full use of both haptic and visual feedback. Last, we intend to design advanced interactive techniques and interaction metaphors to enhance, in a general manner, the navigation possibilities in VR systems.

6.2.2.1. Perception of ground affordances in virtual environments

We have started to evaluate the perception of **ground affordances in virtual environments** (VE). The concept of affordance, introduced by the psychologist James Gibson, can be defined as the functional utility of an object, a surface or an event. In order to test this perception, we considered the affordances for standing on a virtual slanted surface. Participants were asked to judge whether a virtual slanted surface supported upright stance. The perception was investigated by manipulating the texture of the slanted surface (Wooden texture vs. Ice texture).

Our results showed an effect of the texture: the perceptual boundary (or critical angle) with the Ice texture was significantly lower than with the Wooden texture. These results reveal that perception of affordances for standing on a slanted surface in virtual reality is possible and comparable to previous studies conducted in real environments.

Taken together, these results reveal that perception of ground affordances for standing on a slanted surface in virtual reality is possible and comparable to previous studies conducted in real environments. More interestingly, it appears that virtual information about friction can be detected and used in VE and seems to be an important factor involved in the perception of affordances for standing on virtual grounds.

This work was presented at IEEE Virtual Reality conference [56].

6.2.2.2. *Walking Up and Down in Immersive Virtual Worlds: Novel Interaction Techniques Based on Visual Feedback*

In [51] we have developed novel interactive techniques to simulate the sensation of walking up and down in virtual worlds based on visual feedback. Our method consists in modifying the motion of the virtual subjective camera as function of the variations in the height of the ground. Three effects are proposed: (1) a straightforward modification of the camera's height, (2) a modification of the camera's navigation velocity, (3) a modification of the camera's orientation. They were tested in an immersive virtual reality setup in which the user is really walking and in a desktop configuration where the user is seated and controls input devices.

Experimental results show that our visual techniques are very efficient for the simulation of two canonical shapes: bumps and holes located on the ground under a virtual semi-transparent blue cube. The height and the orientation effects yielded highly positive results in the immersive configuration. Users clearly felt a change in height, and could distinguish in most of the cases whether it was a bump or a hole. The velocity effect seems to be less perceived. Interestingly, in the immersive configuration, the consistent combination of all visual effects together led to the best results and was subjectively preferred by the participants. Experiments suggest also a strong perception of height changes caused by the orientation effect changes (although camera's height remains strictly the same in this case). This is confirmed by the subjective questionnaire in which participants estimated a higher amplitude for bumps and holes simulated with orientation technique. This "orientation-height illusion" opens challenging questions in terms of human perception.

This work was presented at IEEE 3DUI Conference [51].

6.2.2.3. *Perception of bumps and holes with camera motions and footstep sounds*

In [60], an experiment has been conducted which goal was to investigate the role of sound and vision in the recognition of different surface profiles of bumps and holes in a walking scenario. Participants were asked to interact with a desktop system simulating bumps, holes and flat surfaces by means of audio, visual and audio-visual cues. The visual techniques used to simulate the act of walking over bumps and holes were the same proposed in [51]. The technique adopted to render bumps and holes at auditory level has been the placement of footsteps sounds at different temporal intervals.

Results of the first experiment could show that participants are able to successfully identify the surface profiles provided through all the proposed audio-visual techniques with very high success rates. The addition of audio stimuli did not produce higher percentages for the recognition of the surfaces rather than the visual only modality which is already very high and close to 100 percents. In addition, the role of dominance between audio and visual modalities has been investigated by means of a second experiment in which conflicting audio-visual stimuli were presented. Results show clearly that in presence of audio-visual conflicts audio is dominated by vision when H and O effects are presented. Conversely, vision is dominated by audio when V and HOV effects are presented. In particular the highest role of dominance has been found for audio stimuli respect visual stimuli provided by means of the Velocity effect. Last, a subjective questionnaire revealed, for the criteria investigated, a clear and significant preference for the bimodal stimuli respect to the stimuli presented in the single modalities.

This work was presented at ACM VRST conference [60].

6.2.2.4. "Shake-Your-Head": Revisiting Walking-In-Place for Desktop Virtual Reality

The Walking-in-Place interaction technique was introduced to navigate infinitely in 3D virtual worlds by walking in place in the real world. The technique has been initially developed for users standing in immersive setups and was built upon sophisticated visual displays and tracking equipments.

In [58], we have proposed to revisit the whole pipeline of the Walking-In-Place technique to match a larger set of configurations and apply it notably to the context of desktop Virtual Reality. With our novel "Shake-Your-Head" technique, the user is left with the possibility to sit down, and to use small screens and standard input devices such as a basic webcam for tracking. The locomotion simulation can compute various motions such as turning, jumping and crawling, using as sole input the head movements of the user. We also introduce the use of additional visual feedback based on camera motions to enhance the walking sensations.

An experiment was conducted to compare our technique with classical input devices used for navigating in desktop VR. Interestingly, the results showed that our technique could even allow faster navigations when sitting, after a short learning. Our technique was also perceived as more fun and increasing presence, and was generally more appreciated for VR navigation.

This work was presented at ACM VRST conference [58].

6.2.3. Pseudo-haptic feedback

Participants: Anatole Lécuyer [contact], Maud Marchal.

Pseudo-haptic feedback is a technique meant to simulate haptic sensations in virtual environments using visual feedback and properties of human visuo-haptic perception. Pseudo-haptic feedback uses vision to distort haptic perception and verges on haptic illusions. Pseudo-haptic feedback has been used to simulate various haptic properties such as the stiffness of a virtual spring, the texture of an image, or the mass of a virtual object.

In [50], we have studied a novel "pseudo-haptic effect": the influence of visual feedback on the tactual perception of both speed and spatial period of a rotating texture. To do so, participants were placed in a situation of perceptual conflict concerning the rotation speed of a cylindrical texture. Participants touched a cylindrical texture of gratings rotating around its axis at a constant speed, while they watched a cylinder without gratings rotating at a different speed on a computer screen. Participants were asked to estimate the speed of the gratings texture under the finger and the spacing (or spatial period) of the gratings.

We observed that the tactual estimations of both speed and spacing co-varied with the speed of the visual stimulus, although the cylinder perceived tactually rotated at a constant speed. The first effect (speed effect) could correspond to the resolution of the perceptual conflict in favor of vision. The second effect (spacing effect) is apparently surprising, since no varying information about spacing was provided by vision. However, the physical relation between spacing and speed is well established according to every day experience. Thus, the parameter extraneous to the conflict could be influenced according to previous experience.

The two cross-modal effects demonstrated here could be of great interest for the designers of haptic devices and virtual reality systems. Our results suggest indeed that the use of a constant haptic (tactile) stimulus can be combined with varying visual stimuli to generate a wide range of haptic sensations. This implies new uses and requirements for the design of cheap and simple tactile peripherals, augmented by visual feedback.

This work has been presented at the Eurohaptics conference [50].

6.2.4. *Interactions within 3D virtual universes*

Participants: Thierry Duval [contact], Valérie Gouranton [contact], Alain Chauffaut, Bruno Arnaldi, Laurent Aguerreche, Cédric Fleury, Rozenn Bouville Berthelot.

Our work focuses upon new formalisms for 3D interactions in virtual environments, to define what an interactive object is, what an interaction tool is, and how these two kinds of objects can communicate together. We also propose virtual reality patterns to combine navigation with interaction in immersive virtual environments.

6.2.4.1. *Generic interaction tools for collaboration*

We have compared different kinds of manipulation metaphors [27] that rely on the generic interaction protocol that we proposed last year, and proposed several Reconfigurable Tangible Devices to improve 3D co-manipulation of virtual objects [28].

6.2.4.2. *Synchonization for collaborative interactions*

We have made a state of the art about the main mechanisms proposed for synchronisation of Collaborative Virtual Environments [40], then we proposed our own way to improve this synchronisation [39], which is partially integrated in the first Collaviz prototype [34] (see section 8.2.5).

6.2.4.3. *The immersive interactice virtual cabin (IIVC)*

The objective of the Immersive Interactive Virtual Cabin [38] is to improve the user's immersion with all his real tools and so to make the design and the use of 3D interaction techniques easier, and to make possible to use them in various contexts, either for different kinds of applications, or with different kinds of physical input devices.

6.2.4.4. *Interoperability and collaborative interaction*

One of the goals of the Part@ge project 8.2.6 is to describe the interactive and collaborative properties of virtual objects when loading universes in 3D formats like Collada or X3D. The next step is to offer interoperability between virtual objects that are described using differents formats. This is why we have proposed a generic architecture for enabling interoperability between 3D formats [31].

6.2.4.5. *Coupling Scheme for Haptic Rendering of Physically-based Rigid Bodies Simulation*

Interactions with virtual worlds using the sense of touch, called haptic rendering, have natural applications in many domains such as health or industry. For an accurate and realistic haptic feedback, the haptic device must receive orders at high frequencies, especially to render stiff contacts between rigid bodies. Therefore, it is today still challenging to provide consistent haptic feedback in complex virtual worlds. Thus, we proposed a new coupling scheme for haptic display of contacts between rigid bodies, based on the generation of a sub-world around the haptic interaction. This sub-world allows the simulation of physical models at higher frequencies using a reduced quantity of data. We introduced the use of a graph to manage the contacts between the bodies. Our results show that our coupling scheme enables to increase the complexity of the virtual world without having perceptible loss in the haptic display quality.

This work has been published in the International conference Eurohaptics [42].

6.2.5. *Visual Attention Models and Gaze-Tracking*

Participants: Sébastien Hillaire [contact], Anatole Lécuyer, Gaspard Breton, Rémi Cozot, Nizar Ouarti, Tony-Regia Corte, Jérôme Royant.

Gaze-trackers are systems that enable the acquisition of user's gaze position on the screen. As for today, reliable systems either require high expertise or are too expensive, whereas low-cost systems often results in poor accuracy. Our research in this area has been conducted following two major axis: (1) a novel way to combine any existing gaze tracking systems to a visual attention model in order to improve their accuracy, and (2) the proposition of a novel visual attention model able to evaluate in user's gaze position on the screen during real-time first-person navigation in interactive 3D virtual environments.

6.2.5.1. Using a Visual Attention Model to Improve Gaze Tracking Systems in Interactive 3D Applications

As for today, none of the existing gaze-tracking systems take into account what the user is looking at on the screen.

In this first research axis, we introduce a novel method using of a visual attention model to improve the accuracy of any gaze tracking system [12]. Visual attention models simulate the selective attention part of the human visual system. For instance, in a bottom-up approach, a saliency map is defined for the image and gives an attention weight to every pixel of the image as a function of its colour, edge or intensity.

Our algorithm uses an uncertainty window, defined by the gaze tracker accuracy, and located around the gaze point given by the tracker. Then, using a visual attention model, it searches for the most salient points, or objects, located inside this uncertainty window, and determines a novel, and hopefully, better gaze point. This combination of a gaze tracker together with a visual attention model is considered as the main contribution of the paper. We demonstrate the promising results of our method by presenting two experiments conducted in two different contexts: (1) a free exploration of a visually rich 3D virtual environment without a specific task, and (2) a video game based on gaze tracking involving a selection task.

Our approach can be used to improve real-time gaze tracking systems in many interactive 3D applications such as video games or virtual reality applications. The use of a visual attention model can be adapted to any gaze tracker and the visual attention model can also be adapted to the application in which it is used.

6.2.5.2. A Real-Time Visual Attention Model for Predicting Gaze Point During First-Person Exploration of Virtual Environments

Our last research axis involve the development of a novel visual attention model to compute users gaze position automatically [45], i.e. without using any harware gazetracking system.

The visual attention model we propose is specifically designed for real-time first-person exploration of 3D virtual environments. It is the first model adapted to this context which can compute, in real-time, a continuous gaze point position instead of a set of 3D objects potentially observed by the user. To do so, contrary to previous models which use a mesh-based representation of visual objects, we introduce a representation based on surface-elements instead of meshes. Our model also simulates visual reflexes and the cognitive process which takes place in the brain such as habituation or the specific gaze behavior associated to first-person navigation in virtual environments. Our visual attention model combines the bottom-up and top-down components to compute a continuous gaze point position on screen that hopefully matches the users one.

We have conducted an experiment to study and compare the performance of our method with a state-of-the-art approach. Our results are found significantly better with more than 100a gaze point in a 3D virtual environment is possible and is a valid approach as compared to mesh-based approaches.

6.3. Visual rendering

6.3.1. Real-time rendering for multiview autostereoscopic displays

Participants: Kadi Bouatouch [contact], Christian Bouville, Rémi Cozot.

Multi-view auto-stereoscopic displays are now available at affordable cost and are getting widely used in virtual reality applications and 3D games. With their wide viewing zone, this type of display easily accommodates multiple viewers and does not require any head tracking. We have tested various virtual cameras settings with a view to keep the region of interest within the usable depth range of the display. We have also developed rendering methods allowing the generation of the interlaced multi-view image on the GPU. Our method accounts for the depth of field effect in case of multi-view auto-stereoscopic display. Real-time rendering on these displays poses a number of difficult problems: (1) real-time generation of several views of the same 3D scene, (2) choice of a particular sampling pattern of the displayed image requiring specific anti-aliasing procedures that results in a limitation of the usable depth range. We have already started to tackle these problems and hope to find out efficient solutions.

6.3.2. *Bayesian Monte Carlo for rendering*

Participants: Kadi Bouatouch [contact], Christian Bouville, Ricardo Marques.

Bayesian Monte Carlo (BMC) techniques are widely used in the domain of Machine Learning, and relies on priors over the function of interest to improve Monte Carlo computations. We have used BMC integration to speed-up the final gathering operation needed in global illumination computation.

Choosing a prior for the incoming luminance function needs to be done carefully in order to effectively reduce variance. In addition, BMC integration requires inversion of large matrices, which can negate the advantages of casting less rays. We have proposed an adequate pre-computing scheme which does not introduce bias in the estimation. We have also proposed a more efficient method for determining optimal distributions of the samples, yielding then more accurate integration. Our work now is to make use of Bayesian Monte Carlo (BMC) for interactive global illumination of animated scenes. The BMC approach will be used to solve the sampling problem in different applications such as: environment map, final gathering, glossy reflection, supersampling for aliasing, upsampling for animation, etc.

6.3.3. *Cinematic relighting*

Participants: Kadi Bouatouch [contact], Vaclav Gassenbauer.

A number of relighting algorithms have been proposed to speed up the recomputation of the image of static scenes. Hasan et al. A relighting algorithm has been proposed for recomputing images including both direct and indirect lighting. Indirect lighting computation is formulated as a linear transformation that transforms direct lighting on a large set of points to indirect lighting on another one. However, the algorithm can only be applied for image relighting for a fixed view point. Using the algorithm for lighting design in animation sequences is not supported. Lighting designed for one frame of the animation sequence does not provide any information about image lighting of the successive frames. We are devising an algorithm for relighting images of an animation sequence. Changing the parameters of light sources and playing back the animation could be done interactively. Following the work of Hasan et al., we have formalized the problem of animation relighting using a transfer tensor. We have proposed a practical optimization of the clustered principal component analysis (CPCA) used for tensor compression. We have exploited the efficiency of linear operations executed on sparse vectors represented in the wavelet basis for speeding up the tensor compression.

6.3.4. *High quality rendering*

Participants: Kadi Bouatouch [contact], Bernardt Duvenhage.

Irradiance Caching is one of the most widely used algorithms to speed up global illumination. We have proposed an algorithm based on the Irradiance Caching scheme [18] that allows us (1) to adjust the density of cached records according to illumination changes and (2) to efficiently render the high frequency illumination hanges. To achieve this, a new record footprint is proposed. While the original method uses records having circular footprints depending only on geometrical features, our record footprints have a more complex shape which accounts for both geometry and irradiance variations. With our method, the record density depends on the irradiance variations. Strong variations of irradiance (due to direct contributions for example) can be integrated in the recorded data structure and can be rendered accurately. Caching direct illumination is of high importance, especially in the case of scenes having many light sources with complex geometry as well as surfaces exposed to daylight. Recomputing direct illumination for the whole image can be very time-consuming, especially for walk-through animation rendering or for high resolution pictures. Storing such contributions in the irradiance cache seems to be an appropriate solution to accelerate the final rendering pass. Our irradiance caching method has been extended to isotropic participating media for multiple scattering simulation.

From the literature, it is known that backward polygon beam tracing (i.e. beam tracing from the light source) methods are well suited to gather path coherency from specular (S) scattering surfaces. This is of course useful for modelling and efficiently simulating caustics (LS+DE paths). We have generalized backward polygon beam tracing [35] to also model glossy (G) scattering surfaces. The efficiency of backward beam tracing in gathering path coherency may therefore now also be exploited to render LGDE transport paths. Using glossy backward

beam tracing one is able to render single scatter caustics that compare well with a 80k photon map while using a relatively low number of scattered glossy beams.

We have proposed a fast and simple method [10] for adding high-frequency shadows into the foliage of trees rendered in real-time. When leaves of a tree project shadows onto other leaves, determining the relationships between cast shadows and the corresponding occluders is a difficult task. We have prposed a method that exploits this difficulty to quickly determine shadows from leaves to other leaves. To this end, we have simulated the presence of these shadows rather than projecting them exactly. The characteristics of these simulated shadows (movement, parallax, size, softness and color) evolve realistically when the lighting conditions change. Our method is fast and supports soft shadows.

6.4. Autonomous and expressive virtual humans

6.4.1. *Virtual reality to analyze interaction between humans*

Participants: Richard Kulpa [contact], Franck Multon, Julien Bilavarn, Bruno Arnaldi, Stéphane Donikian.

Understanding interaction between humans is very challenging because it addresses many complex phenomena including perception, decision-making, cognition, social behaviors. Consequently, defining a protocol for studying a subset of those phenomena is really complex for real situations. Using VR to standardize experimental situations is a very promising issue: experimenters can accurately control the simulated environment, contrary to real world.

In the past, in collaboration with M2S (University Rennes 2), we have worked on the interaction between two opponents in handball. We have designed a framework to animate virtual throwers in a reality center and to analyze the gestures of real goalkeepers whose objective was to intercept the corresponding virtual balls. This VR framework was then validated by showing that behaviors in real and virtual environment were similar.

These works have been extended by using perception-action coupling and perception-only studies to evaluate the anticipation of opponents [9]. In order to evaluate the importance of perceived parameters, the ball and/or the character animation was successively hidden to determine their importance [21] and the same kind of study was done on the graphical level of details [23].

These works have been extended to the study of deceptive movements [11] and gaps evaluation [24] in rugby. Combining perceptual analysis based on the use of cutoffs with biomechanical analysis, we have extracted important kinematic information that could explain differences between experts and novices. Indeed, thanks to the cutoffs, it is possible to determine how early each of these two levels of practice can perceive the correct final direction of the opponent. Then this information is correlated to kinematical parameters of this player.

Finally, we have made some experiments in order to evaluate the perception of the interaction between a real subject and virtual characters during navigation [52].

At last, current studies are experimented in order to know if training of sports in virtual reality can be useful in real situations. The goal is to define training tools that can be used by coaches in order to train athletes to repetitive motions such as katas in karate.

This work will continue to involve specialists in sports sciences (M2S of University Rennes 2) and neuroscientists (Queen's University of Belfast).

6.4.2. *Toward realistic crowd simulation*

Participants: Julien Pettré, Anne-Hélène Olivier, Jan Ondrej, Richard Kulpa, Samuel Lemercier, Jonathan Perrinet.

In the everyday exercise of controlling their locomotion, humans rely on their optic flow of the perceived environment to achieve collision-free navigation. In crowds, in spite of the complexity of the environment made of numerous obstacles, humans demonstrate remarkable capacities in avoiding collisions. Cognitive science work on human locomotion states that relatively succinct information is extracted from the optic flow to achieve safe locomotion. We explored in [15] a novel vision-based approach of collision avoidance between walkers that fits the requirements of interactive crowd simulation.

By simulating humans based on cognitive science results, we detect future collisions as well as the level of danger from visual stimuli. The motor-response is twofold: a reorientation strategy prevents future collision, whereas a deceleration strategy prevents imminent collisions.

Several examples of our simulation results show that the emergence of self-organized patterns of walkers is reinforced using our approach. The emergent phenomena are visually appealing. More importantly, they improve the overall efficiency of the walkers' traffic and avoid improbable locking situations.

6.4.3. *Realistic interactions between real and virtual humans*

Participants: Julien Pettré, Anne-Hélène Olivier, Jan Ondrej, Richard Kulpa, Yijiang Zhang.

Validating that a real user can correctly perceive the motion of a virtual human is first required to enable realistic interactions between real and virtual humans during navigation tasks through virtual reality equipment. In [53] we focus on collision avoidance tasks. Previous works stated that real humans are able to accurately estimate others' motion and to avoid collisions with anticipation. Our main contribution is to propose a perceptual evaluation of a simple virtual reality system. The goal is to assess whether real humans are also able to accurately estimate a virtual human motion before collision avoidance. Results show that, even through a simple system, users are able to correctly evaluate the situation of an interaction on the qualitative point of view. Especially, in comparison with real interactions, users accurately decide whether they should give way to the virtual human or not.

6.4.4. *Dynamics in humanoid motions*

Participants: Franck Multon [contact], Ludovic Hoyet.

Purely motion-capture based techniques do not guarantee physical correctness of synthetic motions. It is however possible to re-process resulting motions to respect the basic laws of Physics. Extending some previous results that used pose adjustments to enforce physical laws such as body weight, we have considered, this year, the issues related to external forces applied on the character.

We have worked in collaboration with LAAS/CNRS (Locanthrope ANR project) in order to clarify how the ZMP (Zero Moment Point) behaves in human walking and for unbalanced motions (leading to a fall). The results demonstrate that there is no relevant criterion in the literature that can predict the actual balance status of human being in highly dynamic situation. This work has been validated on a wide set of subjects and motions (from static to highly dynamic motions).

We also carried-out a perceptual experiment to analyze the minimal noticeable difference perceived by people when watching to motions subject to physical constraints. The results demonstrate [26] that people can also perceive 3kg difference when watching to humans being lifting 2 to 10kg dumbbells while statistical analyzes enabled us to highlight significant difference in joint kinematics even for 1kg difference. We also demonstrated that joint velocities provide relevant information to evaluate the external physical constraints associated with the motion [26].

According to this knowledge, we have designed an innovative animation framework to adapt motions of virtual humans subject to various physical constraints, such as pushing, pulling, carrying or displacing various objects. This method consists in simplifying physics: solving static equations instead of dynamic equation and then applying motion retiming to deal with the joint velocity that has been identified as relevant in the perceptual and biomechanical analysis. Using direct adaptations inspired from biomechanics, it is possible to animate more than 30 characters at 30Hz while taking various physical constraints into account.

All this work was carried out in collaboration with Taku Komura, Edinburgh University, who co-supervises the PhD-thesis of Ludovic Hoyet.

6.4.5. *ToD & DyP : Topology Detection and Dynamic Planning*

Participants: Fabrice Lamarche [contact], Thomas Lopez.

When automatically populating 3D geometric databases with virtual humanoids, modeling the navigation behavior is essential since navigation is used in most exhibited behaviors. In many application fields, the need to manage navigation in dynamic environments arises (virtual worlds taking physics laws into account, numerical plants in which step stools can be moved,...). This study focuses on the following issue: how to manage the navigation of virtual entities in such dynamic environments where topology may change at any time i.e. where unpredictable accessibility changes can arise at runtime. In opposition to current algorithms, movable items are not only considered as obstacles in the environment but can also help virtual entities in their navigation.

The proposed algorithm splits that problem into two complementary processes: ToD (Topology Detection) and DyP (Dynamic Planning) [49]. The aim of ToD is to continuously detect and update topological relations between moving objects i.e. accessibility or obstruction. To compute accessibility relations, ToD relies on the navigation capabilities of a virtual human (climbing a step, jumping etc). The aim of DyP is to use the topology computed by ToD in order to maintain / compute a roadmap enabling accurate path planning inside the dynamic environment. The coupling between ToD and DyP helps to tackle the problem of planning inside dynamic environments at different granularities while precisely identifying elements that require to be updated. This enhances global system performances by enabling local adaptation that can be computed only when required.

6.5. Interactive scenario languages for virtual worlds

6.5.1. *Collaboration between real users and virtual humans for training*

Participants: Bruno Arnaldi [contact], Valérie Gouranton, Stéphanie Gerbaud, Andrés Saraos Luna.

We have proposed models to extend the possibilities of a virtual environment for training to training on collaborative procedures where real users and virtual humans collaborate. First an activity model for the actors allows the dynamic substitution of a real user by a virtual human. This model makes an actor perform actions depending on his capabilities, on the scenario, on the environment and also on his partners' activities. We have also extended the scenario language LORA in order to describe collaborative scenarios. Such a scenario describes the assignment of people to actions and integrates some collaborative actions. The scenario has been simplified while making some basic actions implicit such as taking or putting back an object. Finally, we developed an action selection mechanism. Its aim is, on one hand, to enable a virtual human to select an action to perform and, on the other hand, to give some pedagogical advice to a trainee about the best action to choose. These models have been integrated to GVT in a prototype and validated thanks to two applicative scenarios. The first one consists in collaboratively assembling a piece of furniture delivered in a kit whereas the second one is a collaborative military procedure which consists in preparing a tank to fire. Virtual environments for training, especially collaborative ones, require adaptability in order to be used in various situations. We have identified two levels of adaptation needed by those environments. The first one concerns the application setting. The second one is a dynamic adaptation, at runtime. Our proposed models fully satisfy those needs. These scientific contributions have been integrated to GVT software (see section 5.5).

In the ANR Corvette 8.2.7, new scientific contributions are proposed.

6.5.2. *Virtual Cinematography*

Participants: Marc Christie [contact], Fabrice Lamarche, Christophe Lino.

The domain of Virtual Cinematography explores the operationalization of rules and conventions pertained to camera placement, light placement and staging in virtual environments. In 2010, two major challenges were tackled: (i) the provision of a real-time automated cinematography system capable of wide variations in the elements of Directorial Style to enforce, and (ii) the design and implementation of a low-level pixel-accurate evaluator of the satisfaction of cinematographic properties (eg. degree of occlusion of a character, spatial relationships between elements on the screen).

Our real-time cinematography system is designed around (i) the notion of Director Volume (a spatial partition in the area of appropriate viewpoints which represents a characteristic shot), (ii) a filtering technique operated over the Director Volumes which uses spatial reasonning to encode classical editing rules (*e.g.* Line of Interest, 30 degree angle between shots, and change in size) and (iii) a numerical optimization to compute the best composed shots following rule of the third composition guidelines. The expressive power of the framework is demonstrated by the capacity of our system to perform a large variation in the cinematographic styles it enforces through the control of pacing, camera dynamicity, and composition (published in the Symposium on Computer Animation [48]).

The second challenge is related to the proposal of an expressive language to measure the intrisinc quality of a shot through the evaluation of specific cinematographic properties. Our rationale is to express most properties listed in the litterature, through our language, and compare both their quality and degree of approximation ([33]).

Finally progress has been made in the domain of automated lighting computation [44]. Scientific dissemination of our research topic is provided through the creation and animation of the following website (http://cameracontrol.org).

6.5.3. *Modelling of interactive virtual worlds*

Participants: Rémi Cozot [contact], Fabrice Lamarche [contact], Christian Bouville, Noémie Esnault.

Delivering interactive virtual worlds requires the modeling of the geometry of the 3D world but also the modelling of the interactive and autonomous behaviors of objects, actors and camera embedded in the virtual world. Even if many works try to propose user-friendly GUI to model the behaviours, this task remains a programming task which unfortunately requires strong programming skills. Our main focus here is to explore and propose semi-automatic ways to model the world and the behaviors of objects including virtual actors and camera.

In order to easily build Web 3D interactive worlds from large sets of data, we have proposed a framework based on current websites design pipeline that is distinguished by content management, graphic charter design and interface design. Moreover, our solution must reach a sufficient level of flexibility in terms of extensibility, of modularity, of genericity of input and output file formats, as well as of range of interfaces potentially feasible by designers [36] [37]. Thus we have proposed a software environment allowing metaphor-based information presentation, taking into consideration both the data structure (how the user explores and discovers data) and the visual aspect of the computed environment (the geometry and data representation). These metaphors may be used to visualize large volumes of information coming from databases or classic/semantic search results. The created environments may be highly varying, from 3D interfaces to 3D worlds inside which the user can navigate with an avatar and interact with other users.

6.6. Immersia Virtual Reality room

Participants: Georges Dumont [contact], Alain Chauffaut, Ronan Gaugne.

The team was the first in France to host a large-scale immersive virtual reality equipment known as Immersia. This platform is dedicated to real-time, multimodal (vision, sound, haptic, BCI) and immersive interaction. We are currently installing a new wall with four faces: a front, two sides and a ground. Dimensions are 9.6 m wide, 2.9 m deep and 3.1 m hight. This project will therefore establish a new host structure offering a virtual-reality room with full visual and sound immersion. It will accommodate experiments using interactive and collaborative virtual-reality applications that have multiple local or remote users. The visual reproduction system will combine eight Barco Galaxy NW12 projectors and three Barco Galaxy 7+ projectors. Visual images from Barco projectors are rendered on glass screens. They are adjusted for the user's position, and this, together with their high resolution and homogeneous colouring, make them very realistic. The ART localization system, constituted of 12 ARTtrack (2 and 3) cameras, enables real objects to be located within the U-shape. Sound rendering is provided by a Yamaha processor, linked either to Genelec speakers with 10.2 format sound or Beyer Dynamic headsets with 5.1 virtual format sound, controlled by the user's position.

7. Contracts and Grants with Industry

7.1. Contracts with Industry

7.1.1. *Nexter: Generic Virtual Training*

Participants: Bruno Arnaldi [contact], Stéphanie Gerbaud, Valérie Gouranton.

The GVT (Generic Virtual Training) project (INRIA, Nexter-group and ENIB) is a very challenging one. Indeed, in this project, we introduce advanced VR technology in order to produce customizable VR applications dedicated to industrial training. All our developments are totally re-usable in industrial training, and are not dedicated to a particular industrial equipment and procedure. While our partner ENIB is concerned by the pedagogic part of the training, we focus our activity into the following points. First the design of true reactive 3D objects (including complex objects such as virtual humans) with embedded behaviors thanks to the STORM model. Then the design of high level specification language, LORA, in order to describe complex and potentially collaborative human activity (virtual activity in relationship with the real activity). The scientific contributions are presented in 6.5.1. Since october, we have begin an ANR project, called CORVETTE, see section 8.2.7.

The GVT project led to the deposit of 5 french patents and 1 European patent, and 2 PhD have been defended. More information on the product can be found in section 5.5.

8. Other Grants and Activities

8.1. Regional Initiatives

8.1.1. *Studio Virtuel Nouvelle Génération*

Participants: Rémi Cozot [contact], Fabrice Lamarche [contact], Coralie Delahaye, Claudie Tertre.

This project is founded by the Britany council and involves two local companies (Artefacto, Bilboquet) and the Bunraku team of INRIA Rennes. It aims at creating a virtual studio for broadcast productions. It focuses on three main aspects which are (1) being able to create scenarios and interactively control interactions between virtual (characters for instance) and real (lights, presenter...) elements, (2) to enhance superimposing in order to achieve a visual unity between real and virtual elements and (3) to offer suitable graphic interfaces facilitating the conception / realization of such interactive production.

INRIA is involved in two aspects of the project. The first aspect deals with chroma key and calibration. During the shooting, actors are captured in front of a green screen. The aim of the chroma key technique is to remove this green screen in the background of the scene, and to replace it by another picture or video. In order to achieve visual unity between real and virtual images (colorimetry and luminosity), we apply characteristics of the real data to the virtual images (e.g. automatic white balance). The second aspect concerns scenario languages and behavior modeling. We are creating a new language dedicated to the description of interactive scenarios including interactions between virtual elements (virtual characters, virtual objects) and real elements (presenter for instance). The emphasis is placed on the usability and extensibility of the provided language while offering powerful paradigms dedicated to the description of active virtual elements and their potential capabilities.

8.1.2. *System@tic : online Digital Production*

Participants: Stéphane Donikian [contact], Fabrice Lamarche [contact], Sébastien Maraux, Daniel Trusca.

The On-Line Digital Production project (OLDP) is a project of the national industrial cluster "system@tic" driven by EADS, including many industrial partners (Dassault Systems, Dassault Aviation, Altis, ILOG, Intercim, Trochet, Golaem) and academic partners (CEA, Supmeca, INRIA) that started in june 2009. The goal of this project is to develop technologies that enable an on-line and collaborative digital production modeling, simulation and execution. It extends results obtained during digital plant 1 & 2 projects.

INRIA is involved in the work package number 5 entitled "on-line experimentation services for digital production"'. We are currently working, in collaboration with Golaem company, on the integration of the industrial versions of TopoPlan (known as Golaem Path), MKM (known as Golaem motion) and HPTS++ (known as Golaem coordinator) in Dassault's online software architecture.

8.2. National Initiatives

8.2.1. *ANR Open-ViBE2*

Participants: Laurent Bonnet, Alain Chauffaut, Thierry Duval, Laurent George, Anatole Lécuyer [contact], Jozef Legény, Yann Renard, Aurélien Van Langhenhove.

OpenViBE2 is a 3-year project funded by the French National Agency for Research. The objective of OpenViBE2 is to propose a radical shift of perspective about the use of Brain-Computer Interfaces (BCI). First, in OpenViBE2 we consider 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 is not seen as a replacement but as a complement of classical HCI. Second, we aim 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).

One major strength of OpenViBE2 consortium relies on the fact that four partners were already involved in the previous ANR project OpenViBE1 (2005-2009): INRIA, INSERM, GIPSA-LAB, CEA. In addition, six partners have joined OpenViBE2 to bring their complementary expertise required by the scope of our proposal: CHART, CLARTE, UBISOFT, BLACK SHEEP, and KYLOTONN.

In parallel, the OpenViBE2 consortium contributes to the free and open-source software OpenViBE, which is devoted to the design, test and use of Brain-Computer Interfaces (see Section 5.6).

8.2.2. *ANR SignCom*

Participants: Stéphane Donikian [contact], Franck Multon, Florian Nouviale.

SignCom is a 3-year project funded by the French National Agency for Research. SignCom involves academic and industrial partners: VALORIA lab. (**Project leader**, University of Bretagne Sud, Vannes), IRIT lab. (Toulouse), M2S lab. (University of Rennes 2), Bunraku team (IRISA), and Polymorph Software firm (Rennes), WebSourd firm and IRIS association are external providers (Toulouse).

SignCom aims to improve the quality of the real-time interaction between real humans and virtual agents, by exploiting natural communication modalities such as gestures, facial expressions and gaze direction. Based on French Sign Language (FSL) gestures, the real and virtual humans produce statements towards their interlocutor through a dialog model.

The final objective of the project consists in elaborating two innovative multimodal interactive applications (using body, hand, gaze and face data), producing new ways of communication by recognizing FSL utterances, and synthesizing adequate responses with a 3D avatar. One of the recognition application, developed by the IRIT lab, is based on vision and uses a gaze and face tracking device (Facelab from Seeing machine). The other one, which is currently developed by the Bunraku team in the context of the reality center, uses a multimodal approach, involving full-body motion recognition through several data flows in real-time, including body motion data (using the ART tracking system), gaze and facial expression data (using the same Facelab system) and hand data (using the 5DT cybergloves). The synthesis is developed by the VALORIA lab. From recorded FSL sequences, multimodal data are retrieved from a dual-representation indexed database (semantic and raw data), and used to generate new FSL utterances.

For more information, see: http://www-valoria.univ-ubs.fr/signcom/.

8.2.3. *ANR Locanthrope*

Participants: Julien Pettré [contact], Stéphane Donikian, Jan Ondrej.

Locanthrope is a national project funded by the French Research Agency (ANR). The project is leaded by Jean-Paul Laumond, researcher at CNRS, LAAS, Toulouse.

The human body is a complex mechanical system with numerous body segments. The project LOCAN-THROPE argues that part of the internal cognitive state of a walking person may be observed from only few parameters characterizing the shape of the locomotor trajectories. It aims at providing computational models of human locomotion as a way to simulate and plan human-like actions and interactions in both Robotics and Computer Animation. By computational models we mean models that are effective to be processed by simulation and planning algorithms. LOCANTHROPE is multidisciplinary basic research project gathering four teams in robotics (LAAS, CNRS), computer animation (Bunraku team, INRIA), biomechanics (M2S, University of Rennes 2) and neurosciences (LPPA, Collège de France) respectively.

8.2.4. ANR Pedigree

Participants: Julien Pettré [contact], Stéphane Donikian, Samuel Lemercier.

Pedigree is a national project funded by the French Research Agency (ANR). The project is leaded by Pierre Degond, professor at the University Paul Sabatier in Toulouse (III). Partners are: Institute of Mathematics of Toulouse (IMT) of University Paul Sabatier, Research centre on Animal Cognition (CRCA) of University of Toulouse, Theoretical physics laboratory (LPT) of University of Paris-south and INRIA Bunraku Team in Rennes.

The goals of the project are the experimental and theoretical study of the formation of spatio-temporal structures within moving human groups and the development of realistic mathematical and simulation models of crowds based on these experimental data. The present project aims at investigating these structures through a detailed quantitative study realized at different scales, with the aid of modeling and mathematical tools classically used in applied mathematics and statistical physics. Our goal is to better understand the role of the various (physical and behavioral) parameters which control and modulate these structures in perfectly controlled and standardized conditions and to propose efficient control strategies which allow the management of pedestrian groups and crowds. Crowd modeling and simulation is a challenging problem which has a broad range of applications from public safety to entertainment industries through architectural and urban design, transportation management, etc. Common and crucial needs for these applications are the evaluation and improvement (both quantitatively and qualitatively) of existing models, the derivation of new experimentally-based models and the construction of hierarchical links between these models at the various scales.

8.2.5. ANR Collaviz

Participants: Thierry Duval [contact], Valérie Gouranton, Cédric Fleury, Laurent Aguerreche.

Collaviz is an innovative multi-domain remote collaborative platform (project ANR-08-COSI-003-11 funded by the french national research agency) for the simulation-based design applications.

Collaviz involves 6 Academic partners (ECP, EGID, INPT, INSA Rennes, LIRIS, Scilab) and 11 Industrial partners (Artenum, BRGM, Distene, Faurecia, Medit, MCLP Consulting, NECS, Oxalya, TechViz, Teratec)

The major value brought by Collaviz to the scientific and industrial community is to make remote analysis and collaboration easily available and scalable. Web-based technologies, on the top of shared high-performance computing and visualization centers, will permit researchers and engineers handling very large data sets, including 3D data models, by using a single workstation, wherever in the world. Just a "standard" internet connexion will be needed. The classical approach is not adapted anymore: simulation-based design applications tend to generate Terabytes and even Petabytes of data.

Collaviz deals with four major challenges:

- To provide applications designed for habits of very different communities (geophysics, fluid dynamics, structure, biochemical, drug design...),

- To use mainstream technologies for the service access (low bandwidth internet access, standard hardware for visualization...),

- Interactive and participative collaboration, not only remote "shared display" visualization.

- Moreover, these technologies have to be accessible easily, and Collaviz will provide the proper tools to manage all the services from a user and administrator point of view, to have a full transparent access to these scalable resources: visualization clusters, grid computing, etc.

We are leading the WP4 about Collaborative Virtual Environments and Techniques, whose aim is to manage the 3D collaborative interactions of the users. During 2010 we contributed to the first Collaviz prototype by providing a first version of a collaboration service. Scientific contributions are presented in [40], [34], [38].

8.2.6. ANR Part@ge

Participants: Bruno Arnaldi [contact], Laurent Aguerreche, Alain Chauffaut, Georges Dumont, Thierry Duval, Cédric Fleury, Loïc Tching.

Part@ge is a national research platform (project 06TLOG031 funded by the french ANR) composed by 6 Academic partners (INSA Rennes, INRIA I3D, INRIA Alcove, CNRS-LaBRI, CNRS-LMP, ESIA Laval), 8 Industrial partners (FT R&D, CEA LIST, Clarté, HAPTION, Renault, Virtools, Sogitec, Thalès). There are also some participants of the part@ge club: Inergy, SNCF, DCN, EDF, Barco, PCI.

The Part@ge project, whose aim is to provide new tools and solutions for collaboration within 3D virtual environments, is decomposed into four technical Work Packages:

- Models and Objects for Collaborative Virtual Environments,

- Communication and Presence,

- Advanced Collaboration,

- Integration, Usability and Evaluation.

We are leading the project, participating to the four work packages and are leading one of them related to advanced collaboration. The Part@ge project is based on OpenMASK (our VR-platform), Spin3D (the FT R&D VR-platform) and Virtools.

We have animated the Part@ge workshops of the year, participated to numerous smaller work sessions with our partners about our points of interest, presented demos at the Laval Virtual 2010 exposition, and presented during a public session the final state of the project.

8.2.7. ANR Corvette

Participants: Bruno Arnaldi [contact], Valérie Gouranton, Andrés Saraos Luna.

Corvette (COllaboRative Virtual Environment Technical Training and Experiment) aims to propose a set of scientific innovations in industrial training domain (maintenance, complex procedures, security, diagnostic, ...) exploiting virtual reality technologies. This project has several scientific axes : collaborative work, virtual human, communication and evaluation.

Corvette involves 3 Academic partners (INSA Rennes, ENIB, CEA-List) and 3 Industrial partners (Nexter Training, Virtualys, Golaem).

The main breakthroughs are :

- Collaborative Work : define an effective cooperation between a real human and an autonomous virtual human with a definition of a model for complex scenarios and actions.

- Virtual Human : define an unified model for kinematic, kinetic and dynamic constraints.

- Communication : permit the virtual human communicative behaviors in order to enrich the interaction real human-virtual human.

- Evaluation : define a set of criteria and indicators to measure the cognitive phenomena in part of a collective experiment, represent the tangible elements of performance.

We (INSA Rennes) are leading the ANR Corvette.

8.3. European Initiatives

8.3.1. *NoE: Integrating Research In Interactive Storytelling*

Participants: Stéphane Donikian [contact], Marc Christie [contact], Nicolas Pépin, Julian Joseph.

The IRIS project (Integrating Research in Interactive Storytelling) is a 3-year Network of Excellence project funded by the European Commission (FP-7 Grant Agreement 231824) gathering 10 academic partners: University of Teeside (project coordinator UK), INRIA (FR), Fachhochschule Erfurt (DE), TECFA Geneve (CH), Vrije Universiteit Amsterdam (NL), Universitat Augsburg (DE), Université La Rochelle (FR), OFAI Vienne (AT) and Newcastle University (UK).

IRIS (Integrating Research in Interactive Storytelling) aims at creating a virtual centre of excellence that will be able to achieve breakthroughs in the understanding of interactive storytelling and the development of corresponding technologies. It is organised around four major objectives:

- To extend interactive storytelling technologies in terms of performance and scalability, so that they can support the production of actual interactive narratives
- To make the next generation of interactive storytelling technologies more accessible to authors and content creators of different media backgrounds (scriptwriters, storyboarders, game designers)
- To develop a more integrated approach to interactive storytelling technologies, achieving a proper integration with cinematography
- To develop methodologies to evaluate interactive storytelling systems as well as the media experience of interactive narrative

8.3.2. *STREP: NIW*

Participants: Gabriel Cirio, Anatole Lécuyer [contact], Maud Marchal, Tony Regia Corte, Léo Terziman.

The Natural Interactive Walking Project (NIW) is a 3-year project funded by the European Commission under the FET Open STREP call. NIW involves 5 partners: INRIA/BUNRAKU, University of Verona (leader), University of Aalborg, University of Paris 6, and McGill University. The Natural Interactive Walking (NIW) project aims at taking advantage of multisensory information about the ground to develop knowledge for designing walking experiences. This will be accomplished through the engineering and perceptual validation of human-computer interfaces conveying virtual cues of everyday ground attributes and events. Such cues may be conveyed by auditory, haptic, pseudo-haptic, and visual augmentation of otherwise neutral grounds. The project is focused on creating efficient and scalable display methods across these modalities that can be easily and cost-effectively reproduced, via augmented floors and footwear.

It is expected that the NIW project will contribute to scientific knowledge in two key areas. First, it will reinforce the understanding of how our feet interact with surfaces on which we walk. Second, it will inform the design of such interactions, by forging links with recent advances in the haptics of direct manipulation and in locomotion in real-world environments. The methods that will be created could impact a wide range of future applications that have become prominent in recently funded research within Europe and North America. Examples include floor-based navigational aids for airports or railway stations, guidance systems for the visually impaired, augmented reality training systems for search and rescue, interactive entertainment, and physical rehabilitation.

More information can be found on Natural Interactive Walking project website : http://www.niwproject.eu/

8.3.3. *STREP: TANGO*

Participants: Julien Pettré [contact], Stephane Donikian, Jonathan Perrinet.

Tango is a EU FP7 Fet-Open STREP project (2010-2013). Tango is coordinated by Beatrice de Gelder, professor at the University of Tilburg, The Netherlands. Partners are: Max Planck Institute, Germany, The Weizmann Institute of Science, Israel, University of Tuebingen, Germany, INRIA, France, La Sapienza - University of Rome, Italy, and the ETHZ, Switzerland.

Many everyday actions take place in a social and affective context and presuppose that the agents share this context. But current motion synthesis techniques, e.g. in computer graphics, mainly focus on physical factors. The role of other factors, and specifically psychological variables, is not yet well understood. The goal of the TANGO project is to take these familiar ideas about affective communication one radical step further by developing a framework to represent and model the essential interactive nature of social communication based on non-verbal communication with facial and bodily expression.

8.3.4. *INFRA: VISIONAIR*

Participants: Georges Dumont [contact], Bruno Arnaldi [contact], Valérie Gouranton, Maud Marchal, Alain Chauffaut, Ronan Gaugne.

Our actual Virtual Reality systems allowed us to be a key partner within the European Project VISIONAIR that was accepted this year (and will begin in 2011) in the infrastructure call of FP7. Our Virtual Reality room is now, in Europe, a key place for virtual reality. We are leading a Work Package (WP9 on Advanced methods for interaction and collaboration) of this project and are deeply involved in the scientific piloting committee. The VISIONAIR project's goal is to create a European infrastructure that should be a unique, visible and attractive entry towards high level visualisation facilities. These facilities will be open to the access of a wide set of research communities. By integrating our existing facilities, we will create a world-class research infrastructure enabling to conduct frontier research. This integration will provide a significant attractiveness and visibility of the European Research Area. The partners of this project have proposed to build a common infrastructure that would grant access to high level visualisation and interaction facilities and resources to researchers. Indeed, researchers from Europe and from around the world will be welcome to carry out research projects using the visualisation facilities provided by the infrastructure. Visibility and attractiveness of ERA will be increased by the invitation of external projects. This project is build with the participation of 26 partners (INPG ENTREPRISE SA IESA France , Institut Polytechnique de Grenoble France, University of Patras LMS Greece, Cranfield University United Kingdom, Universiteit Twente Utwente Netherlands, Universitaet Stuttgart Germany, Instytut Chemii Bioorganicznej Pan Psnc Poland, Universite De La Mediterranee D'aix-Marseille II France , Consiglio Nazionale Delle Ricerche CNR Italy, Institut National de Recherche En Informatique et en Automatique INRIA France, Kungliga Tekniska Hoegskolan Sweden, Technion - Israel Institute of Technology Israel, Rheinisch-Westfaelische Technis- che Hochschule Aachen RWTH Germany, Poznan University of Technology Poland, Arts et M ?etiers ParisTech AMPT France, Technische Universitaet Kaiserslautern Germany, The University of Salford United Kingdom, fraunhofer-gesellschaft zur foerderung der Angewandten Forschung Germany, fundacio privada I2CAT Spain, University of Essex United Kingdom, Magyar Tudomanyos Akademia Szamitastechnikai Es Automatizalasi Kutato Intezet Hungary,Ecole Centrale de Nantes France, University College London United Kingdom, Politecnico di Milano Polimi Italy, European Manufacturing and Innovation Research Association, a cluster leading excellence).

8.4. International Initiatives

8.4.1. *BIRD*

Participants: Stéphane Donikian, Julien Pettré, Franck Multon, Yijang Zhang, Georges Dumont.

Our team works in collaboration with the CAD&CG State Key lab at the Zhejiang University in China on two topics. Both have a common objective: enabling interactions between virtual and real humans. The first topic deals with the real-time animation of virtual humans in interaction with real humans. The problem is then to measure real humans' motions, interpret them, and make a virtual human react and move accordingly. The second topic deals with augmented reality. Our objective is to build a mixed-reality world shared by both real and virtual humans. The foreseen application is to enable navigation of real humans among a real environment populated by virtual walkers. A joint-PhD, Yijang Zhang, between our two teams is currently working on this latter topic.

8.4.2. *PRC CNRS: Smart Motion Planning*

Participants: Marc Christie [contact], Fabrice Lamarche [contact], Thomas Lopez.

This Cooperative Research Project is a collaboration with Prof. Tsai-Yen Li, head of the Intelligent Media Laboratory located in Taiwan. This project looks at exploring the integration of topological and semantic information in the planning of motions in virtual environments. Motion planning is a complex and critical problem that finds applications in a large range of research fields. Results from the field of robotics have long-time been projected onto planning issues in virtual spaces, and have been adapted to character motion planning (autonomous agents, crowed simulation) and camera path planning (object tracking, virtual visits, virtual cinematography), however only considering the problem at a geometric level. In this project, we propose to make a fundamental and qualitative step in motion planning for virtual environments by integrating topological and semantic information in the exploration of navigable search spaces. We propose to extract multi-level abstractions of the geometric representation, offering detection of application-specific patterns (e.g. bottlenecks, staircases, doorways), to further allow the extension of classical planning techniques towards qualitative reasoning. The dynamic aspects of targeted applications include the necessity to design locally and globally informed reactive techniques.

8.4.3. *JST-CNRS: Improving the VR experience*

Participants: Anatole Lécuyer [contact], Gabriel Cirio, Thierry Duval, Maud Marchal, Ludovic Hoyet, Léo Terziman.

This project is supported by the Strategic Japanese-French Cooperative Program on "Information and Communications Technology (ICT) including Computer Science" and funded both by JST in Japan and CNRS in France. The goal of the project is to take advantage of the french-japanese relationships that were initiated during the STIC France-Asian project in VR (2004-2006), by concretising the exchanges through collaborations around the improvement of immersion in Virtual Reality environments. We aim at enhancing the behavior, visualization, and interaction between entities or between the user and the entities evolving in these virtual worlds. At the end, the expected results are an improvement of the realism in immersive environment, in particular of expressiveness, intelligent behavior of entities, and interactive gestures to communicate intuitively with these entities.

A. Lécuyer, T. Duval, L. Hoyet, and L. Terziman, notably attended the fourth meeting in Sendai in November 2010.

8.4.4. *RTR2A*

Participants: Kadi Bouatouch [contact], Jonathan Brouillat, Christian Bouville.

We have another collaboration with the graphics group of the technical university of Minho, Braga, Portugal. The objective is to make use of Bayesian Monte Carlo (BMC) for interactive global illumination of animated scenes. The BMC approach will be used to solve the sampling problem in different applications such as: environment map, final gathering, supersampling for aliasing, upsampling in animation, etc. A PhD thesis is jointly supervised by two professors, one from the university of of Minho and the other from the university of Rennes 1 and member of the Bunraku team.

8.4.5. *Technical University of Prague*

Participants: Kadi Bouatouch [contact], Christian Bouville.

We have another collaboration with the graphics group of the technical university of Prague. The objective is also interactive global illumination of dynamic scenes. The approaches used are different from those followed in the framework of the associate team RTR2A. A PhD thesis is jointly supervised by two professors, one from the technical university of Prague and the other from the Bunraku team who is professor at the university of Rennes 1.

8.4.6. *Technical University of Pretoria*

Participants: Kadi Bouatouch [contact], Christian Bouville.

We have another collaboration with the graphics group of the technical university of Pretoria. From the literature, it is known that backward polygon beam tracing (i.e. beam tracing from the light source) methods are well suited to gather path coherency from specular (S) scattering surfaces. This is of course useful for modelling and efficiently simulating caustics (LS+DE paths). The objective of this collaboration is to generalize backward polygon beam tracing to also model glossy (G) scattering surfaces. The efficiency of backward beam tracing in gathering path coherency may therefore now also be exploited to render LGDE transport paths.

A PhD thesis is jointly supervised by two professors, one from the technical university of Pretoria and the other is a member of the Bunraku team and professor at the university of Rennes 1.

A paper has been presented at the AFRIGRAPH'2010 conference [35]

9. Dissemination

9.1. Scientific Community Animation

- B. Arnaldi: **Vice-Director** of IRISA (UMR 6074), **Member** of the Scientific Committee of Clarté (Technopole de Laval), **Vice-President** of Scientific Committee of INSA, **Member** of the Selection Committee (CSV) of the Competitiveness Cluster "Media and Networks" (http://www.images-et-reseaux.com/) since 2005, **Co-leader** of the Virtual Reality thematic of the Competitiveness Cluster "Media and Networks" since 2005, **Member** of the Managment Committee of "Fondation Métivier" (http://metivier.irisa.fr/), **Vice-President** of AFRV, **Responsible** of the organisation of scientific presentation during the annual days of the association AFRV, **Member** of Evaluation Committee (CE) of ANR/COSINUS, **Co-chair** of VRIC 2010 (Virtual Reality International Conference, Laval), Chair of the white ANR SIMI2 commitee.

- K. Bouatouch: **Member** of the programme committee of WSCG, Pacific Graphics, ISVC, IWSV, **Member** of the Editorial Board of the Visual Computer Journal, **Reviewer** for most of all the computer graphics conferences (Siggraph, Eurographics, EGSR, etc.) and journals (IEEE TVCG, The Visual Computer, Computer Graphics Forum, JCST, TOG), **Responsible** for a collaboration with the computer graphics group of the University of Central Florida and the university of Utah, **External examiner** of multiple PhD committees in US, GB and France.

- C. Bouville: **Member** of the associations ACM, SIGGRAPH, EUROGRAPHICS, **Reviewer** for the conferences WSCG2010, MMVE2010,Web3D2010.

- M. Christie: **Member** of Eurographics and AFIG , **Member** of Program committee and Steering committee of Smartgraphics 2010, **Member** of Program Committee of CASA 2010, **Reviewer** of SIGGRAPH ASIA 2010, Eurographics 2010, Eurographics 2011, Smartgraphics 2010, Pervasise 2011, TVCG, **Co-Editor** of a Special Issue in International Journal on Creative Interfaces in Computer Graphics.

- G. Dumont: **Member** of the Selection Committee (CSV) of the Competitiveness Cluster "Media and Networks", **Member** of the AFRV. Member of IJIDEM Board. Scientific leader of Media and Interaction department of IRISA (UMR 6074). Local chair and organising committee of CASA 2010. Leader of WP9 of VISIONAIR european project to begin in 2011 and member of its scientific committee.

- T. Duval: **Member** of AFIHM and AFRV, **Reviewer** for IEEE VR 2010 and IHM 2010, **Co-chair** of the Informal Communications topic of IHM 2010.

- V. Gouranton: **member** of AFRV, **reviewer** of IEEE Virtual Reality 2011 conference.

- R. Kulpa: **Reviewer** of ACM TOG, **Program Committee member** of CASA 2010, IADIS International Conference Web Virtual Reality and Three-Dimensional Worlds 2010

- F. Lamarche: **Reviewer** for Motion In Games 2010, **Responsible** of the On Line Digital Production Project and of the PRC on Smart Motion Planning.

- A. Lécuyer: **Associate editor** of ACM Transactions on Applied Perception, **Secretary** of the French Association for Virtual Reality, **Secretary** of the IEEE Technical Committee on Haptics, **Member of Selection Committee of ANR CONTINT Call for Project**, **Organizer of Tutorial** at IEEE Virtual Reality 2010 on "Walking through virtual worlds" (Co-organizers: F. Steinicke from Munster Univ., Germany, and M. Ernst from MPI, Germany), **Jury member** of IEEE 3DUI Contest, **Program Committee member** of international conferences in 2010 : IEEE 3DUI, JVRC (IPT-EGVE-EuroVR), VRIC, Cyberworlds, **Reviewer** of journals in 2010 : IEEE ToH, ACM TAP, **Reviewer of conferences** in 2010 : ACM CHI, ACM SIGGRAPH, IEEE 3DUI, Eurohaptics, VRIC, ACM UIST,

- M. Marchal: **Reviewer of international journals in 2010**: Presence, International Journal of Computer-Human Studies, Progress in Biophysics and Molecular Biology **Reviewer of international conferences in 2010:** IEEE EMBS, IEEE Virtual Reality, IEEE 3DUI, ACM SIGCHI, ASME WINVR, VRIC **Symposium co-chair** of "Medicine in Virtual Reality" in VRIC'2010 **Member** of AFRV, **Invited Speaker** in Virtual Prototyping Summer School 2010, **Scientific expert** for French National Agency for Research (ANR TecSan), **External examiner** of one PhD candidate (Université Lille 1)

- F. Multon: **Member** of the Eurographics, IEEE, ACM SIGGRAPH, European Society of Biomechanics, **Reviewer** of CGI'2010, Cyberworlds'2010, Eurographics 2010 (STAR), IEEE VR 2011, VRST'2010, SIGGRAPH ASIA 2010 (Sketchs), **Program Committee** member of IEEE-VR 2010, CASA2010, French Congress of the Biomechanics Society, **Invited Speaker** in Motion in Games 2010 (Zeist, Netherlands), **Guest Editor** of a special issues entitled "VR and Sports" in Presence journal (MIT Press), **Co-organizer** of the "Simulation of Sports Motion" colocated with CASA 2011 in China.

- J. Pettré: **Reviewer** for IEEE ICRA, Eurographics, Siggraph Asia; **Reviewer of Journal** for Zhejiang University-SCIENCE, IEEE CGA and Computer Animation and Virtual World; **Member** of ACM; **Organization Committee member** of CASA 2010; **Program Committee member** of CASA, Motion in Games, Pacific Graphics; **In charge of Workpackages for** ANR PSIROB 2007 Locanthrope, ANR SYSCOMM 2008 Pedigree, EU FP7 Fet-Open STREP TANGO; **External examiner** of PhD candidates: Tan-Viet-Anh (LAAS-CNRS)

9.2. Courses in Universities

- B. Arnaldi: Computer Science MASTER OF COMPUTER SCIENCE, MR2I Ifsic, INSA de Rennes: Virtual and Augmented Reality (VAR) (with E. Marchand), **Responsible** for the Track Images and Interactions of the MASTER OF COMPUTER SCIENCE, MR2I Ifsic, INSA de Rennes, Virtual Reality course, Master 2 INSA of Rennes.

- K. Bouatouch: Responsible for a course DIIC INC (IFSIC) on Image Synthesis (with R. Cozot and F. Lamarche), **Responsible** for a the thematic track "Image and Interaction" of the MASTER OF COMPUTER SCIENCE (IFSIC), **Responsible** for a course of the MASTER OF COMPUTER SCIENCE (IFSIC) : Coding Transmission and Rendering of Video, Audio and 3D Data (CTR).

- R. Cozot: Mobile Multimedia MASTER OF COMPUTER SCIENCE GL, MITIC, AND MIAGE, ISTIC, UNIVERSITY OF RENNES 1.

- G. Dumont: full Associate Professor - 100h (because of leading the team), involved in different courses in Mechanics and virtual reality for master students at Ecole Normale Supérieure de Cachan and University of Maine (MNRV), involved in Mechanical Agregation course at ENS Cachan (mechanical science, plasticity, finite element method), **Responsible** of MASTER 2 mechatronics ENS CACHAN/RENNES 1 University.

- M. Christie : Courses HCI, Android system, Computer Graphics and Animation, University of Nantes.
- T. Duval: DIIC LSI, MASTER OF COMPUTER SCIENCE GL AND MITIC Ifsic : Man-Machine Interfaces and Design of Interactive Applications, MASTER OF COMPUTER SCIENCE Ifsic : Introduction to Computer Graphics, MASTER OF COMPUTER SCIENCE Ifsic : Collaborative Virtual Environments.
- V. Gouranton: responsible of the Course Introduction to Virtual Reality, INSA de Rennes.
- F. Lamarche: Computer Animation DIIC INC, ESIR IN (with K. Bouatouch), Real Time Rendering and Computer Animation MASTER GL, MASTER MITIC, ISTIC - MIT, ENS CACHAN ANTENNE BRETAGNE.
- A. Lécuyer: Haptic Interaction MASTER MNRV, UNIV. ANGERS (with K. Bouatouch), Brain-Computer Interfaces and Haptic Interfaces MASTER SIBM, UNIV. RENNES 1.
- F. Multon: MASTER OF COMPUTER SCIENCE Ifsic : **Responsible** of Image and Motion; MASTER OF PHYSICAL EXERCISE University Rennes2
- M. Marchal : Modeling and Engineering in Biology and Health Applications, Complexity, Object-Oriented Modeling and Programming INSA RENNES, Medical Simulation MASTER SIBM, UNIVERSITÉ RENNES 1; MASTER IMA, TELECOM PARISTECH AND UNIVERSITÉ PARIS 6

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