INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Bunraku

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

Rennes - Bretagne Atlantique

THEME COG

Activity Report

2007

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2. Overall Objectives

2.1. Overall Objectives

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*. Let us explain now what is behind this definition. 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 problem 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. Moreover, interaction can be of different natures: functional, physical, kinematics and cognitive. Today, user interaction in a VR application is mainly driven by the physical interaction of the user, while in the same time virtual humans have minimal physical capacities. One of the main objectives of Bunraku concerns the concurrent management of different natures of interaction. First of all, the 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. For example, if someone wants to perform a training session involving collective activities and nobody else is currently in the loop, virtual humans should be able to supply the user needs by replacing missing real ones. To reach this ambitious objective we have to develop expressive autonomous human-like characters, able to perform in real-time complex and believable actions. A virtual human has at least two usages in a virtual reality environment, the first one is to represent a real human in the virtual world and it is then called an avatar, and the second one is to live autonomously inside the virtual environment, that is to say, perceive, decide and act on its own. Both uses require a geometrical representation of the human, but in the second case it is also necessary to model the control activity instead of reproducing the activity of a real character. Concerning the motion control of virtual humans, we have to increase the introduction of dynamic laws and physical capabilities inside our model to produce more complex and credible motions. The use of dynamic into our model will increase the number of situations that can be managed. In the same time, we have also to take account of two very significant constraints: real-time and controllability. We are also working on parameterizable and expressive motion models. 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. This is one of our challenges for the next years, and for that we have to provide an answer to the symbol grounding problem to combine in a generic way cognition with a reactive embodied and situated human character. To tackle the embodiment of cognitive symbols we have to develop a complex hierarchy of perception decision action loops, by managing the bidirectional exchange 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. At the moment, motion control and behavior model are usually seen as two independent software components, which does not allow a good solution for prediction and adaptation to the context. We have to provide a better integrated solution, allowing the management of adaptable and expressive models of motion. A new dimension concerns the integration of social rules to manage interpersonal relations and especially the notion of groups inside crowds. Another original contribution concerns the multi-level modeling approach for crowd simulation. It allows us to take into account both reactive and cognitive behavior of virtual humans inside complex and realistic environments such as a train station, including the management of their individual activities upon time. An important task concerns the calibration and validation of our model on real case studies, which fortunately is possible due to our fruitful partnership with the French railway company.

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. 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 narration. To propose a generic scenario language, we have to formalize the different natures of interaction. This is the first step toward the development of high level scenario languages. As some VR applications require also to make cooperate several software components executed on an heterogeneous 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.

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 proposal, in complement of the individual evolution of the research activity on each field, we want to reach a new stage concerning their integration in a common federative research program.

Our objectives are now decomposed into three complementary research themes:

- Multimodal Interaction with objects within the world;
- Expressive Autonomous Characters;
- Interactive scenario languages.

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 behaviour 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, behavioural simulation, real-time simulation, haptic and multimodal interaction, collaborative interaction and modeling of virtual environments.

3.2. Dynamic models of motion

Keywords: *animation*, *hybrid systems*, *identification*, *levels of detail*, *movement*, *simulation*.

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, example: position and velocity.

The use of 3D objects and virtual humans inside a virtual environment imply to implement dedicated dynamic models. However, the wished 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 coming from mechanics. The general formulation of these equations is non-linear second order (in time) differential system coupled with algebreaic equations (DAE: Differential Algebraic Equation):

$$\underline{\underline{M}}(\overrightarrow{q})\overline{q} = \overrightarrow{N}(\overrightarrow{q}, \overline{q}, t)$$

where $\overrightarrow{N}(\overrightarrow{q}, \overline{q}, t)$ are the actions and non-linear effect (Coriolis) and $\overrightarrow{q}$ are the output parameters describing the system. In case of $\overrightarrow{q}$ 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:

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

where $\underline{\underline{\sigma}}$ is the stress tensor in the material and is related to the deformation tensor $\underline{\underline{\varepsilon}}$ by the relation $\underline{\underline{\sigma}} = \underline{\underline{\underline{\underline{A}}}}\underline{\underline{\varepsilon}}$ ($\underline{\underline{\underline{\underline{A}}}}$ 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 are to be solved by approximation methods (Finite Element Method: FEM) and may be difficult to solve in real time. When contact or collisions occurs, 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 and that is issued from Non-Smooth Contact Dynamics (NCSD) $\underline{\underline{M}}(\overrightarrow{q})d\bar{q} = \overrightarrow{N}(\overrightarrow{q}, \bar{q}, t)dt + \overrightarrow{R}dv$ 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 $\underline{\underline{\varepsilon}}$ 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:

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

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

3.3. 3D interaction

Keywords: *3D Metaphors*, *3D interaction*, *Human-Computer Interaction*.

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 Fitts law (Equation 1) 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.

$$T = a + b.\log_2(\frac{D}{W} + 1) \quad (1)$$

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.

The taxonomy of 3D interaction categorizes classically the techniques according to the task to be achieved in the 3D virtual environment Three types of tasks are usually distinguished: interact with the environment, navigate, and control an application. Quite often, interaction with the environment is the association of a selection task and of a manipulation task, which consists generally in positioning and orienting the selected object(s). Here the first difficulty is to be able to select the object (generally with a method based on ray casting that intersects the geometry of the virtual object). The second difficulty is to propose manipulation metaphors adapted to the interaction situation: in some cases the object can be reached by the user and manipulated with a virtual hand or a virtual 3D cursor within the users workspace, but sometimes this object can not be reached easily and the user must use an interaction tool to select this distant object, and then it is quite difficult to find the good tool to achieve the manipulation of this distant object. Navigation concerns the modification of the users point of view on the virtual world, in order to perceive it differently. It is probably the most frequent interaction technique within virtual worlds. Most of the times, navigation is a preliminary task, but it is a very important one, which allows to be positioned at the *right place*, in order to have an efficient interaction with a virtual object. This task can be quite tedious because the target of the navigation can be difficult to reach and can even be moving. Application control techniques allow to modify the properties and parameters of the virtual world, by editing some of its properties. Here again there is a wide area of research about 3D widgets and other dedicated 3D metaphors.

3.4. Visual Rendering

Keywords: *lighting simulation*, *partitioning*, *rendering*, *visibility*.

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:

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

Where $L()$ is radiance, 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 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 the radiance caching mechanism and exploit the performances of the new graphics cards, even in case 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

Keywords: *Avatars*, *Motion Control Human Behavior*, *Virtual Humans*.

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:

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

where n is the number of degrees of freedom and θ_i is the i^{th} 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 characters center of mass):

$$\Delta\theta = J^{+}(\theta)\Delta X - \alpha(I - J^{+}J)z$$

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 Identity 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. In short, it is necessary to be interested in the operation of various faculties that constitute together the human spirit, without forgetting their relation with the body. In complement of the study of these general mechanisms underlying any human behavior, the work should also concern the study of human faculties in dedicated activities such as navigating in a city, using a work instrument or conducting a structured interview. The comprehension of the human behaviors requires competence in fields as varied as neurosciences, psychology or behavioral biology. Two types of approaches can be distinguished. The first one, known as the symbolic approach, consists in modeling the human behavior in an abstract way in the form of modules describing each one a mechanism and relations of sequencialism or existing parallelism between them. It seeks to describe the mental processes by using symbols, judgements and mechanisms of logical inference. The second approach, known as systemic, consists to look inside the cerebral activity of patients subjected to various stimuli, according to well defined operational protocols. It is focusing more on concepts of signal transmission in networks, control and state feedback. The two approaches have different advantages: the first makes it possible to be abstracted from the biophysics processes present within the brain and to propose a modelling of the behaviour based on competence, while the second approaches, nearer to the neuro-physiological data, will be adapted to the modelling of the neuronal and sensori-motor activities. None of the models proposed in the two approaches is completely satisafactory to model the human behaviour in its whole. Indeed, our problem is not to reproduce the human intelligence but to propose an architecture making it possible to model credible behaviours of anthropomorphic virtual actors evolving/moving in real time in virtual worlds. The latter can represent particular situations studied by psychologists of the behaviour or to correspond to an imaginary universe described by a scenario writer. However, the proposed architecture should mimic all the human intellectual and physical functions.

The important bibliographical study made during last years in the field of cognitive sciences pointed out the diversity, even the antagonism, of the approaches and the absence of federator models to propose an architecture allowing to connect together the various functions used in the human behaviour even for the simplest. The various approaches generally focus on one or the other of the functions or on a particular method of their relation. No theory exists for determining either the necessary or sufficient structures needed to support particular capabilities and certainly not to support general intelligence. There is however a general agreement on the decomposition into several layers or bands going from very low level control loops (reactive level), providing very fast responses to stimuli (sensory-motor control), to higher levels such as the cognitive one manipulating and reasoning on symbols, and the social one including personality, emotions and relation between humans. The reactive layer does not need to explicitly manipulate an abstract representation of the world, while the cognitive layer manages the abstract knowledge representation system. One of the main difficulties in the existing models is that usually symbols manipulated at the upper levels are not grounded into the world in which the lower level is making the virtual human react to its environment. The symbol grounding problem and the Chinese room problem are well known in artificial intelligence. However, there is not any solution today allowing a fully linked integration inside a unified virtual human architecture of both continuous low level situation and embodiment and high level symbolic reasoning.

4. Application Domains

4.1. Panorama

Two classifications can be used. The first one concerns the objective while the second one concerns the domain of activity. They are both represented in the following table. Elements in boxes concern applications developed in the team.

Cognitive Science		BCI	Locomotion Reactive Navigation	BCI Visuo-Haptic Crowds
Manufacturing PLM	Endoscop CAD/VR	Endoscop PERF-RV2	GVT2 PERF-RV2	
Sport			Hand-ball	Hand-ball
Paleoanthropology Art, Culture Entertainment	 Virtual Museum Interactive Drama ConceptMove	 Interactive Choreography ConceptMove		Lucy
Architecture Urbanism	Informed Environment	Crowd Simulation Rendering and navigating through complex scenes	Quality of service	Simulem Collective Behaviors

4.2. Industrial products and process

The applications to the industrial domain seems to be very promising. Let us note, for instance, the PSA Automotive Design Network, which is a new design center. This center groups all the tools used for automotive design, from classical CAD systems to Virtual Reality applications. Renault as also conducted a first attempt to couple the virtual assembling methods into a CAD system. The coupling of virtual reality and simulation algorithms was a key point in the PERF-RV RNTL project in which we have been involved. This coupling is also fundamental in the Salome2 RNTL in which we were involved too. We are currently participating to the Intuition European NoE Project which partly addresses this topic. In the Perf-RV2 ANR/RNTL project and the Digital Plant 1 & 2 Projects of the competitiveness cluster System@tic, we are addressing the problem of human activity in a digital plant.

The major innovations, that we can target, are the following:

- Coupling of Virtual Reality with CAD systems
- Control of the simulations by visualization and virtual reality
- Development of design environments based on simulation of different domains
- Cooperative work
- Virtual assembling and project review.

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. Quality of service inside public mobility areas

The exploitation of large transport facilities, such as railway stations and airports, requires a specific expertise on the crowd phenomenon. To apprehend these phenomena, to adapt to the density fluctuations and to prevent disasters due to a bad appreciation of the safety conditions, it appears convenient to develop powerful tools. In spite of scientific work published in the Seventies by Dr. John J. Fruin, the development solutions, mainly in consulting by British companies rather than on rack, are in general not specialized to a particular activity. It is to carry out a jump of productivity, to make these technologies accessible and to *democratize* their use that we have started a collaboration with AREP and SNCF. We are working together on the *quality of service inside public mobility areas*, and we are designing the first simulation tool dedicated to railway stations in the Simulem Project.

4.5. 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. In the continuity of the PhD thesis work of Benoit Bideau2 on the study of the duel between the real goal-keeper and the virtual fighter in an Hand-Ball game, we this year will extend this model by integrating follow-up of glance of the goal-keeper using an oculometer and a followup of the orientation of the head, but also will use the real-time functionalities of our new motion capture system in order to close again the loop and to allow the virtual fighter to adapt its behaviours to the reactions of the goal-keeper, which was not possible in the preceding version. In a future a little longer, we hope also to address tactical problems in the collective plays, to study and model them. This work is done jointly with the Biomechanics team of M2S (joint lab between the University of Rennes 2 and ENS Cachan).

4.6. Training

Training activities is one of the more challenging applications for the future of Virtual Reality. Indeed, we find in such applications all the arguments regularly quoted in favour of virtual reality: control of the training process, management of the physical devices, security for trainees and for hardware. In industrial maintenance training application we need to define, on one hand, a plausible 3D environment (realistic action and reaction) and, on the other hand, the complex scenario representing the maintenance sequence. This is our purpose in the Work Package 4 of the PERF-RV2 Project and it will be demonstrated on two industrial scenarios, one from Nexter Systems and the other from AFPA. These scenarii must be described using a very rich and powerful language in order to embed as much as possible of the real life complexity. Indeed, the scenario is often the kernel of the application because both the Virtual Reality interactions and the pedagogical aspect of the application are in strong relationship with the scenario. The problematic of integration of complex scenarios in training application is one of our main concerns in the partnership we have with Nexter Systems in the GVT Project (Generic Virtual Training).

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. OpenMASK: Open-Source platform for Virtual Reality

Keywords: *distributed simulator*, *interactivity*, *middleware*, *modularity*, *real-time simulator*, *software platform*, *virtual reality*.

Participants: Alain Chauffaut [contact], Benoît Chanclou, Xavier Larrodé, Michaël Rouillé.

OPENMASK (Open Modular Animation and Simulation Kit) is the 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 (www.openmask.org). The year 2007 will end with a new OpenMASK major release V4.0 .

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). It can be used to describe the behavior or motion control of a virtual object as well as input devices control like haptic interfaces. An OpenMASK application is made of kernels and simulated objects. Objects are frequential or reactive motors. Building a virtual environment with OpenMASK consists of selecting and configuring the appropriate simulated objects, and choosing an execution kernel fulfilling the application needs. Of course, new classes of simulated objects have to be built first if they do not exist. But they can be reused in other applications.

Release V4.0 improves extensibility with smaller units of modularity: extension components, callback mechanisms associated to event listener and C++ plugin mechanisms at application's start.

Main features offered by the OpenMASK kernel:

- Hosting: creation and destruction of simulated objects.
- Naming: simulated objects, classes and attributes are named.
- Activating: regular activation (each object can have its own frequency) and/or occasional one (on event reception) for simulated objects.
- Communicating:
  - using data flows between simulated objects
  - using signal diffusion in the environment
  - using events between objects
  - with adaptation to the different activation models using interpolation and extrapolation
- Time management: automatic data dating and unique time-stamp during computation.
- Distributing: presently powered by Parallel Virtual Machine (PVM). Distribution is transparent to the programmer but could be controlled by the operator.

Visualizer is one of the main components to attend Virtual Reality Applications. Firts ones were powered by Performer (Sgi) or by OpenSG (Fraunhofer Institute). Release V4.0 redefine a new visualization module using Ogre3D. This module also improves extensibility with a better separation between simulated objects and visual objects, with new animator plugs concept. Main features offered by the visualizing object:

- Mono or multi-pipes visualization, adapted for reality centers and workbenches. Multiple views and stereo-vision.
- Support of all geometrical file formats supported by Performer , OpenSG or Ogre3D.
- keyboard and mouse events captures and owner forwards.
- 2D or 3D picking and subscribers forwards.

The new V4.0 release distribution includes the OpenMASK kernel and the Ogre3D visualizer with keyboard and mouse input extensions (Fig. 1). Our reusable C++ basic tools are managed in their own library OBT.

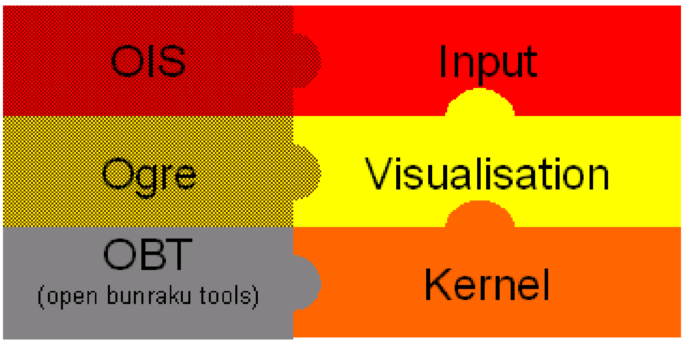


Figure 1. Omk V4.0 layers architecture

For virtual reality community, we provide a set of useful simulated object classes which could be reused by new applications.

- visualizer as described previously
- interaction services over 3D virtual scene
- realtime animation of virtual humans
- management of spatialized sounds
- management of VRPN devices
- management of force feedback devices
- physical scene simulation

These classes are managed into dedicated libraries (Fig. 2). Common ones are into the Add-On library. Theses products may be mixed with external libraries as we do with MKM library to build OpenMASK humanoïd powered by MKM.

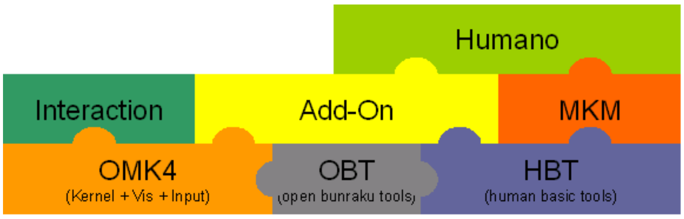


Figure 2. Example of VR OpenMASK application included humanoïd powered by an external tool MKM

Model based tools:

OpenMASK provides an Open C++ API but we also provide Model Driven Tools to facilitate the building of new OpenMASK applications. The main aim of this approach is to free the user of fastidious and repeated coding and to improve reusability. Within Eclipse environment we offer an editor to design simulated object class associated with a C++ code generator. We also offer an editor to build OpenMASK application by selecting the right classes and by instantiating the right objects.

Technology transfer:

Our technology transfer initiative is based on industrials partners and Open-Source distribution. We are supported by INRIA with dedicated resources (ODL 2001/02, ODL 2003/05 and software development engineer 2005/06).

First, we provided only the platform which is of general interest. Now, we are delivering simulated objects dedicated to Virtual Reality, most of them with an Opensource licence: interactors, virtual human, force feedback processor, collisions manager, VRPN peripherical abstractions. OpenMASK is already available on Linux and Windows systems, and soon on Macintosh system.

Theses sources are available on our web site www.openmask.org. We manage also a public wiki for documentations and a public forum for discussion. We entend also to build a public data base dedicated to reusable simulated objects.

5.3. MKM: Manageable Kinematic Motions

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

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.

The first part of this work deals with the reconstruction of captured motion files. It is done off-line within a software that imports motions in most usual formats like C3D (Vicon) or BVH (BioVision) and exports them in a morphology-independent file format which allows to replay the same motion on any avatar in a scene. For captured motions obtained for example with the Vicon system, this software includes the computation of the real joint centers directly from the external markers. This development is based on some researches done in the M2S laboratory. This way, the reconstructed motions are more accurate and nearer from the original ones. Directly from the position of these joint centers, the motions are converted into the morphology-independent representation of the motion.

This representation is based on a simplified skeleton which normalizes the global postural informations. This formalism is not linked to morphology and allows very fast motion retargetting and adaptation to geometric constraints that can change in real-time (cf figure 3). This approach dramatically reduces the post production and allows the animators to handle a general motion library instead of one library per avatar. However motion is not limited to a sequence of postures but also takes intrinsic constraints into account, such as ensuring foot-contacts or reaching targets while grasping objects. We have proposed a xml-based language to design such constraints off-line. A user can then use a graphics interface to edit those constraints and define their beginning, end and properties while playing the captured motion. Those constraints can deal with points of the body or of the environment that both can change during real-time animation. Several types of constraints are addressed with this language: contacts and distances between points, restricted and authorized subspaces for a given point and orientation in space for a given body segment. All those constraints are converted into a unique formalism that enables to solve them thanks to a unique solver.

Figure 3. Six characters with different morphologies replaying the same motion that is also adapted in real time to the evolution of the ground

The second part of the framework provides an animation library which uses the motions obtained from the off-line tool 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. This model automatically converts the user commands into a selection of the most appropriate motions and the parameterization of their relative importance.

At last, in order to create realistic and smooth animations, MKM uses motion synchronization, blending and adaptation to skeletons (in order to deal with different morphology of characters) and to external constraints (such as the position of a target). All those processes are performed in real-time in an environment that can change at any time, unpredictably. As the constraints are associated to time interval during which their weight evolves continuously, the system can solve them at each time without requiring the knowledge of all the sequence.

An inverse kinematic and kinetic solver was developed, based on the morphological-independent representation of posture. The inverse kinematics module allows to verify the kinematic constraints while the inverse kinetics ensures that the balance of the character is preserved. Indeed, the control of the center of mass position allows preventing from some unrealistic postures although all the other geometric constraints are verified. For example, if geometric constraints are placed far in front from the character, he could take a posture that does not verify balance. In order to ensure balance, the user can ask the system to impose that the center of mass is placed on a vertical line going through its initial posture. In that case, we assume that balance is verified in the original captured motion. Our inverse kinematics and kinetics module is based on an improvement of the Cyclic Coordinate Descent method. In this last method, the body segments are rotated individually to solve geometric constraints, leading to unrealistic postures when numerous body segments are used. To overcome this limitation, we gathered some body segments into groups, leading to the use of the minimum set of required body segments and allowing to have a control on the order of the adaptations between and within the groups. Moreover, we also introduced the control of the center of mass position in this algorithm (see figure 4). As a perspective, we wish also to control the Zero Moment Point position in order to deal with balance in very fast and dynamic motions (cf. paragraph 6.14).

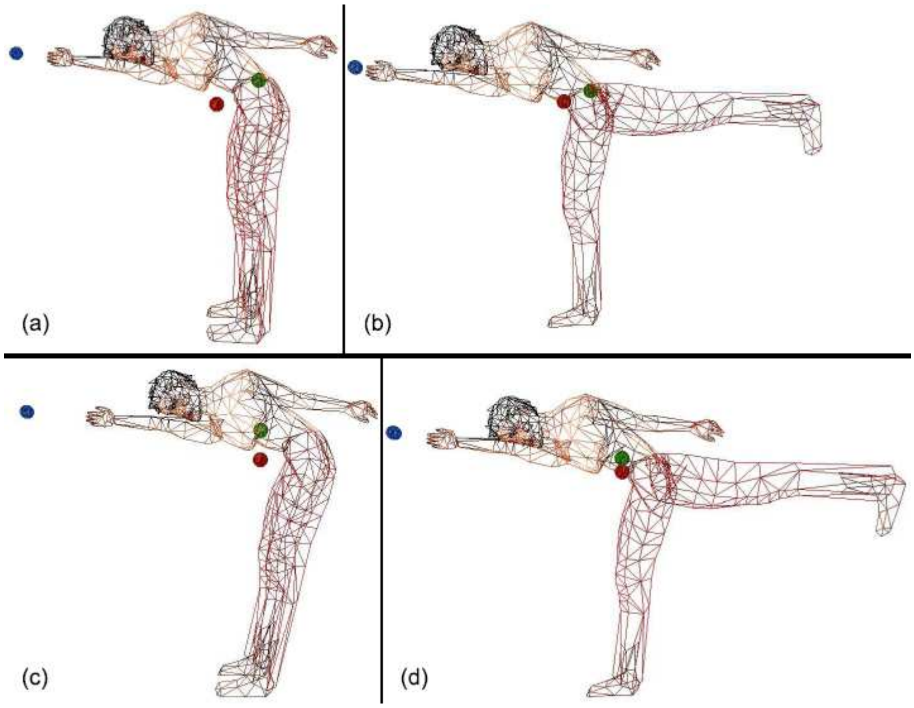


Figure 4. a) grasping without inverse kinetics. b) inverse kinetics has no high priority; the left leg is used to counterbalance the upper-body and the constraint imposed to the wrist is not verified. c) inverse kinetics has high priority but only the root is translated and the constraint is still not verified, but the target is really far. d) inverse kinetics has high priority and combination of the root translation and the left leg rotation is used.

This library has been used in several applications, for example in a virtual museum or a presentation for Imagina 2002. It has been improved in the RIAM project "AVA-Motion", which ended in june 2004, to become a complete, "ready to use", library for industrial companies (it has been presented in SIGGRAPH 2005 exhibition at the INRIA's booth). It has also took part of the RIAM project "Semocap" (which ended in 2006) that involves our partner: M2S, University Rennes 2. It currently runs on Windows and Linux with different viewers and it has been also integrated in three different software architectures: AVA from the Daesign company, OpenMASK (our own platform) and Virtools. This latter is the main professional software in VR simulation but there is only a simple animation module for virtual characters. We have integrated MKM inside Virtools creating several Building Blocks. These modules allow to animate any character inside the Virtools environment using the high level controls of MKM. We are also allowing the user to parameterize the animation directly using the interfaces associated to these Building Blocks. This development is partially funded by the "Numerical Plant" project of the "system@tic" French competitiveness cluster (cf. paragraph 7.5). Another graduate engineer has been recruited in order to connect MKM with HPTS++ (also developed in the Bunraku project) and to consequently provide a library that could be used by industrial partners, as a professional toolbox.

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

Participants: Fabrice Lamarche [contact], Stéphane Donikian [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.

HPTS++ is the last evolution of the HPTS model. Firstly designed for behavioural animation, it provides a generic and platform independent framework to describe multi-agent systems. It is composed of a language allowing agent description through finite state machines and a runtime environment handling parallel state machine execution and offering synchronization 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. It is object oriented: state machines can inherit of other state machines and/or C++ classes to provide easy interfacing facilities. States and transition can be redefined in the inheritance hierarchy and the state machines can be augmented with new states and transitions. Moreover, state machines are objects that can provide a C++ interface (constructor/destructor/methods) for external calls. 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 handles parallel state machine execution and provides synchronization facilities. It includes a recent research work on automatic behaviour synchronization. Each state of a state machine is informed with a set of resources (or semaphores) to specify mutual exclusions between state machines. Each state machine is informed with a priority function specifying its importance at each simulation time step. Each transition is informed with a degree of preference allowing to describe possible adaptations in regard with resource availability or need. Those three properties are combined by a scheduling algorithm in order to automatically and consistently adapt state machines execution with respect to their respective priorities and resource conflicts. Moreover, this algorithm provides an automatic dead lock avoidance mechanism. This property enables independent state machine description and ensures consistent execution without knowledge of their description and without explicit hand coded synchronization. Moreover, the kernel supports dynamic state machine construction and dynamic resource declaration.

This toolkit runs under Windows (Visual C++ 6.0 et .NET), Linux (g++ 2.96 - 3.2) and IRIX systems (CC). It has been used in different research fields such as behavioural animation, scenario description and automatic cinematography. Its scheduling system provides new paradigms for multi-agent systems description while ensuring the overall consistency of the execution.

5.5. GVT : Generic Virtual Training

Participants: Bruno Arnaldi, Nicolas Mollet, Xavier Larrodé, Stéphanie Gerbaud.

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 scenarii, multiple hardware configurations: laptop computer, immersion room (see figure 5), distribution on network, etc.

The actual kernel of GVT platform is divided into three elements that rely on innovative models proposed by IRISA (LORA and STORM models) and by CERV (for differentiated pedagogy). These models as well as the global platform have been presented in [39].

- A Behaviour 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 certain actions. The scenario is written in the LORA language (Language for Object-Relation Application).
- A Pedagogical Engine. This engine, employed to assist the trainer, uses the two engines above to decide what the trainee is allowed to do.

GVT has been described in the ERCIM News magazine [17] and a poster has been presented in the second AFRV days. The main recent evolution of GVT is the integration of the last release of OpenMASK 4.0 which integrates the OGRE 3D engine (see figure 5).

Figure 5. On the left - Immersed training. On the right - The last release of GVT

6. New Results

6.1. Dynamics-based analysis of motions

Keywords: *Dynamics-based Validation*, *Motion Analysis*.

Participants: Nicolas Pronost, Charles Pontonnier, Georges Dumont.

Retargeting and interpolation methods may introduce physical inaccuracies in virtual human animation. We have proposed a method for evaluating the dynamical correctness of retargeted and interpolated motions generated by an editing method. This editing method adapts the motion to a new character and to locomotor parameters thanks to a morphological retargeting and kinematical interpolations in a motion database. An inverse dynamic analysis was used to study the physical accuracy of the adapted motions, by computing the resulting forces and torques at joints.

There are some questions that need to be answered on these adapted motions:

- Are the adapted motions physically valid ?
- How can we use the computed forces and torques to produce physically valid motions?

So a method for evaluating the dynamical correctness of retargeted and interpolated locomotions is proposed. Furthermore, we propose to improve an initial database with analysed motions that are synthesized by using a forward dynamics method. The analysis algorithm consists in determining the resulting forces and torques at joints. With this intention, we develop an automatic creation process of the mass/inertia model of the character. Then using support phase recognition, we compute resulting forces and torques by an inverse dynamics method. The retargeting and the interpolation methods change the physics of the motions. This change is evaluated by using the results of our above proposed analysis on artificial and real motions and by using literature and experimental data from force plates. The evaluation relies on the study of several retargeting and interpolation parameters such as the global size of the character or the structure of the model. The outputs of this evaluation are the resulting forces and torques at the joints that are used to produce physically correct motions by using forward dynamics simulation. With this purpose, we have introduce forces and torques normalizations, and the synthesized motions may then improve the initial database [27]. The method of motion synthesis thanks to forces/torques control can be solved by forward dynamics on a rigid body mechanical model. For the simulation of we have used a mechanical library developed in the team. This library simulate the physical motion of polyarticulated rigid bodies thanks to the automatical computation and resolution of the laws of motion applied on a specific system.

The following system parameters are to be provided to the model:

- The mechanical model (description of the target skeleton): rigid bodies with masses and inertias, and links;
- The initial state of the system: values of the dof and their first time derivate;
- The external forces: gravity and Ground Reaction Forces;
- The motor torques: coming from the dynamics-based analysis and the normalization presented last year

Our first results on human locomotions generated by forward dynamics are presented on figure 6. As mentioned above, the used forces or torques are issued from inverse dynamics analysis possibly performed on other characters. They are normalized according to our method to synthesize these new motions.

We are now trying to apply this approach, mixing captured data and dynamic synthesis, to a human hand. A Phd Thesis work began in september on this subject. The objective is to propose a model of a virtual articulated hand controlled by an interface (a glove, for example) for an utilisation in virtual reality. This study should focus on multibody dynamics, anatomical data analysis, biomechanics of living tissues. We will develop a kinematical model coupled to a muscular model in order to control the motion of the virtual hand. Grasping tasks will certainly be analysed because they are often involved when using a hand. The objective is to propose as natural as possible a model and a simulation tool dedicated to the control of this virtual hand.

6.2. Non smooth multibody dynamics and haptic interaction with objects

Keywords: *Contact*, *Impact*, *Multibody Dynamics*, *Simulation algorithms*, *haptic interaction*.

Participants: Loïc Tching, Georges Dumont.

Dealing with three dimensional frictional contact with impacts is a key point for applications with haptic feedback. The work aims at adapting the outstanding methods in computational mechanics to the real-time constraints induced by Virtual Reality and to couple them with haptic interfaces. Our work is based on the use of *Non Smooth Contact Dynamics* (NSCD) that was studied in our team (postdoctoral position of M. Renouf during 2004-2005 year, jointly with BIPOP team at INRIA Rhône/Alpes). Two major advantages of the method can be exhibited for haptic simulations. The first is that the time-stepping numerical scheme should lead to correctly control the real-time constraints induced by virtual reality. The second is that the impact and contact forces are naturally handled with this method and so could help us to realise a better coupling.

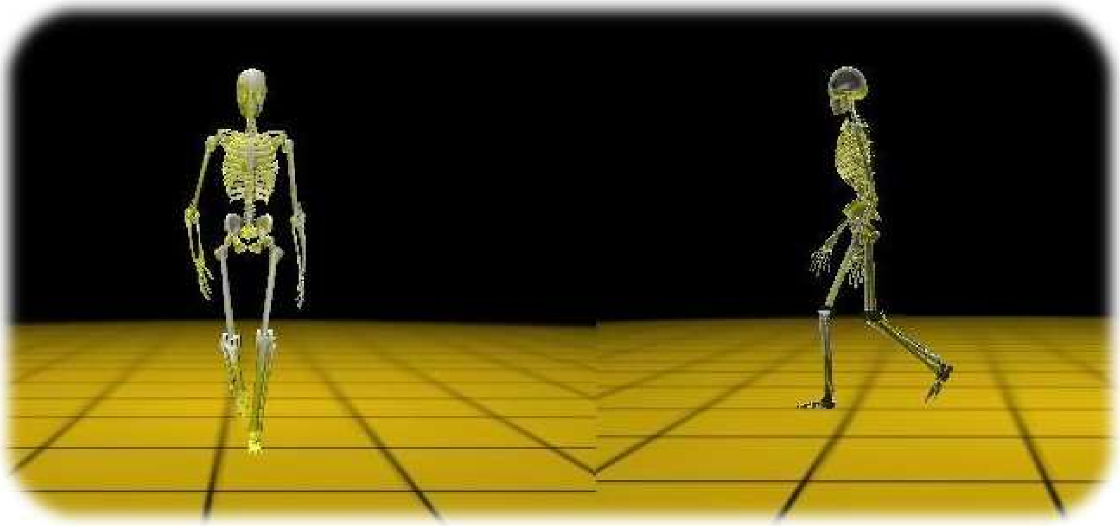


Figure 6. The simulation of a human locomotion with normalized forward dynamics on the same character. The synthesized motion (in gray), is very close to the original motion (in yellow).

The contact/impact phenomenon is as discontinuous one leading to non smooth differential equation. Most of the proposed method to deal with haptic interaction in this case rely on penalty methods. These penalty method are used to regularize the mathematical formulation of the problem and allow to use classical numerical schemes. The major drawback is that it induces a "smoothness" in the haptic restitution and that the penalty coefficient is impossible to fix correctly without trial and error tests.

As an alternative to these previous drawbacks, we want to adapt tools of computational mechanics for simulation of multibody systems. We think that tools based on the Non Smooth Contact Dynamics (NSCD) framework have advantages for haptic simulation. The solving scheme is not handicapped by the change of contact status during the simulation and leads to a unified treatment of collisions and contacts that can be sticking or sliding contacts. More, the time step can be adapted in order to meet the real time constraint for the simulation. Third, no virtual coupling should be necessary to translate forces to positions or positions to forces.

In a virtual environment, a model of solid is built around two entities. As in CAD, the first model is a geometrical one. The second one is the rigid body model that drives the motion through space. So the interactions (contact/impact) treatment is composed of two parts: the first concerns geometrical detection, the second concerns the resolution of equations of motion. Once a geometrical interaction has been detected, one has to modify the resolution of the equations of motion for taking this interaction into account and for ensuring non penetration of the solids. The typical algorithm for this resolution is presented in figure 7.

We will not develop here the framework that was previously developed. We prefer to focus on the coupling with a haptic interface.

In Figure 8), we synthesize the objective of the work. We have to couple a haptic interface (left side of the figure) with a non-smooth dynamics simulation (right side of the figure).

This work is the subject of a Phd Thesis that began in january. This thesis is granted by Haption SA, leader in design and fabrication of haptic devices, by mean of a CIFRE contract with our team. The work is integrated

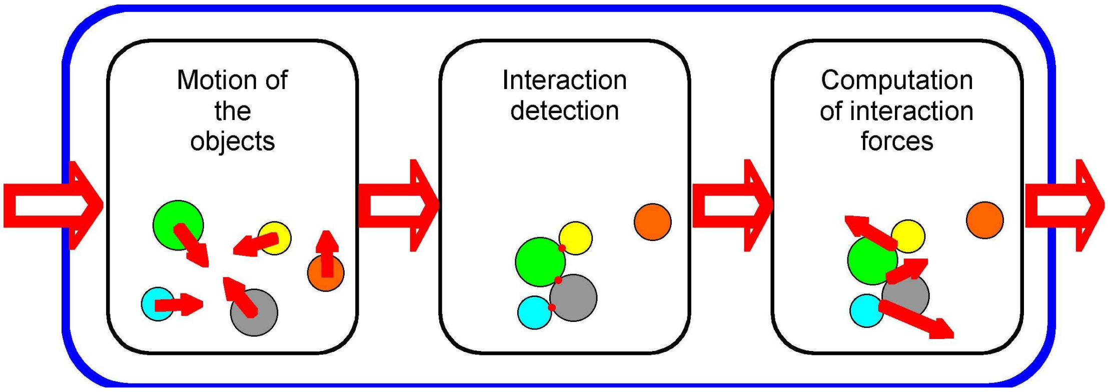


Figure 7. Synoptic of the resolution algorithm

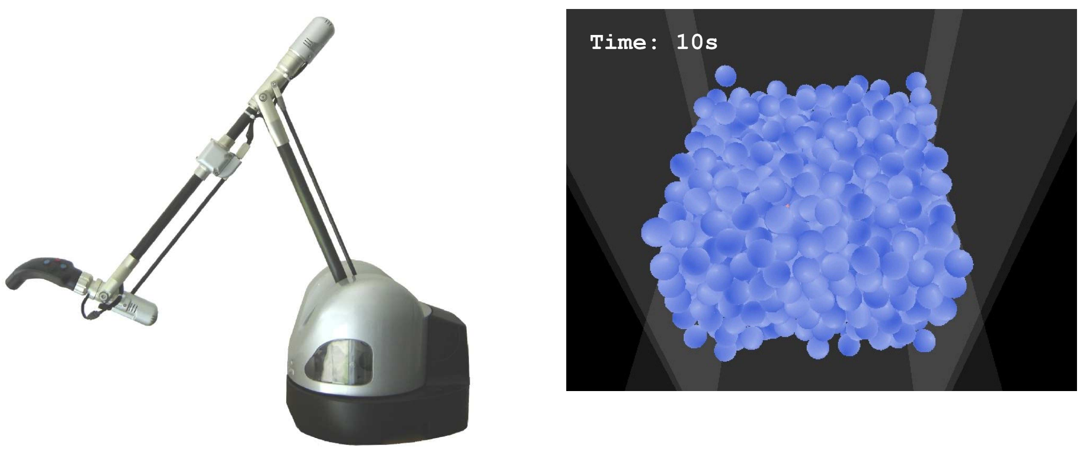


Figure 8. Coupling between a haptic device and a simulation

in the Part@ge ANR project described in this document. In this context, we have proposed a state of the art report that have been submitted for publication in TSI journal.

6.3. Real time multi-resolution analysis of huge digital mock-ups in virtual reality

Keywords: *CAD*, *Computational Results Analysis*, *Huge models*, *Mesh Analysis*, *Multiresolution algorithms*, *Out-of-core Data Structures*, *Virtual Prototyping*.

Participants: Bruno Arnaldi, Georges Dumont, Valérie Gouranton.

The aim of this work is the analysis of huge digital mock-ups in Virtual Reality. This work was the subject of the PhD thesis of Jean-Marie Souffez (July 2006). The goal is to interactively handle these models in a VR scene, to allow their virtual prototyping.

As the digital mock-ups are too large to be straightforwardly handled by a single PC hardware, it is necessary to implement a level-of-detail (LOD) framework,that will control the size of the model at run-time.

The solution that we have implemented is a multi-resolution framework that provides easy out-of-core management of the whole model and ensures direct access to the original mock-up. It is based on a partition of the input mesh into several sub-meshes and on the dual graph of the partition. Several under-samplings are generated for each sub-mesh. Computational results can then be loaded on particular sub-meshes at run-time, allowing fast and easy analysis of the whole model, and allowing local analysis of the model at its original resolution.

The purpose of this work is to extend previous work to improve performance and the proposed analytical capabilities to the user for the transition to very large meshes. To achieve this objective, we focus on serveral points : segmentation methods, multi-resolution representation and grid computations.

6.4. Interactive Global Illumination

Keywords: *GPU*, *Global Illumination*, *Interactivity*, *Irradiance and Radiance Caching*, *Photon mapping*.

Participants: Kadi Bouatouch, Jonathan Brouillat.

We have extended the irradiance caching approach to indirect glossy global illumination. Our algorithm relies on radiance caching. It is based on the caching of directional incoming radiances.

We have also developed the "radiance cache splatting" algorithm which allows to compute global illumination using programmable graphics hardware. Using a reformulation of irradiance and radiance caching, our method relies on the capabilities of GPUs to perform radiance interpolation. Moreover, we developed an efficient, GPU-based method to avoid the need of ray tracing. Our approach yields an overall speedup of $30 - 40\times$ compared to the Radiance software, considered as the reference for irradiance caching.

We devised a novel method for fast, high quality computation of glossy global illumination in complex animated environments. Building on the irradiance caching and radiance caching algorithms, our method leverages temporal coherence by introducing temporal gradients. Using our approach, part of the global illumination solution computed in previous frames is adaptively reused in the current frame. Our simple adaptive reusing scheme allows to obtain fast rendering times while avoiding the presence of flickering artifacts and global illumination ghosts. By reusing data in several frames, our method yields a significant speedup compared to classical computation in which a new cache is computed for every frame.

Radiance cache splatting considers only one-bounce reflection, but runs at interactive frame rates. When the camera moves, additional records have to be computed, which slows down rendering. As radiance cache splatting is view-dependent, the user has to compute records for a certain number of positions and orientations of the camera to get records that could be used by any intermediary camera. This is computationally expensive, and is a tedious task since the user has to move the camera several times to cover the whole scene. This constitutes the drawback of the method. However, once these records have been computed, rendering can be performed in real time. Photon mapping provides multiple-bounce global illumination. In addition, the lighting simulation pass is view-independent. But the rendering pass has to resort to computationally expensive final gathering to compute high quality images. Hence this method can only be used for offline rendering purposes. We have then proposed a method which exploits the advantages of photon mapping and irradiance cache. We wanted to avoid the computationally expensive pass of final gathering. Our algorithm computes an irradiance cache directly from the information contained in the photon map. The cache accounts for multiple-bounce reflections and covers most parts of the scene without any user intervention. The computed cache can then be used with radiance cache splatting for real time rendering.

6.5. Rendering globally illuminated natural scenes

Keywords: *Natural objects*, *Rendering*, *Volume rendering*.

Participants: Kadi Bouatouch, Kévin Boulanger.

Nowadays, computer generated images of natural scenes are getting more and more realistic. Indeed,the targeted goal is to create images that are similar to what the viewer can see in real life withhis/her eyes. The main obstacle in achieving the target is complexity. Nature scenes from real lifecontain a huge number of small details which are hard to model, take a lot of time to render and require a huge amount of memory, unavailable in current computers. This complexity mainly comes from geometry and lighting. The geometric complexity is due to a high number of grass blades or tree leaves for example, a huge number of primitives such as triangles are needed to accurately model them; lighting computation complexity is due to the multiple re°ections of light over the scene objects with complex materials. Overcoming this complexity has been a challenging problem for many years. We address this problem in the context of grass and tree rendering. Algorithms have been developed to render grass and trees in real-time with approximations. Algorithms have also been developed to render them with high quality, for example using raytracing. Even in this latter case, approximations have to be used to render within a reasonable processing time. Our goal is to achieve real-time rendering of nature scenes while providing visually convincing dynamic global illumination. Our approach aims at rendering large amounts of natural elements, such as grass and trees, with approximations that reduce the rendering time while giving the convincing illusion of global illumination in dynamic scenes.

Our method allows the rendering of a soccer field, containing approximately half a billion grass blades, with dynamic lighting in real-time (cf figure 9). It is also capable of rendering complex trees with global illumination computation (cf figure 10).

6.6. Subsurface scattering and eye modeling

Keywords: *GPU*, *Subsurface Rendering*, *Translucent Objects*, *eye modeling*, *refraction*.

Participants: Kadi Bouatouch, Guillaume François.

We have designed and implemented a software for real-time rendering of subsurface scattering within translucent materials. Subsurface scattering within translucent objects is a complex phenomenon. Designing and rendering this kind of material requires a faithful description of their aspects as well as a realistic simulation of their interaction with light. Our contribution is a new method for modeling and rendering complex organic materials made up of multiple layers of variable thickness. The material modeling is based on simple texture mapping principle, called Subsurface Texture Mapping. Our rendering method calculates the single scattering contribution for this kind of material in real-time using commodity graphics hardware. The single scattering computation requires the calculation of distances traversed by a light ray through a translucent object for evaluating the attenuation of light within the material. We have proposed a fast surface approximation algorithm to evaluate these distances. Our whole algorithm is implemented on the GPU.

Figure 9. Views of a grass field

Figure 10. Trees

Figure 11. Subsurface scattering within skin : appearance of veins

Rendering of human face principally focused on skin modeling and rendering using multiple methods, such as texturing, diffusion approximation and the recent multi-pole based method. Recovering anatomical features of organic materials is a challenging issue. The human eye, as an important part of the non verbal communication, needs to be accurately modeled and rendered to increase the realism of virtual characters.

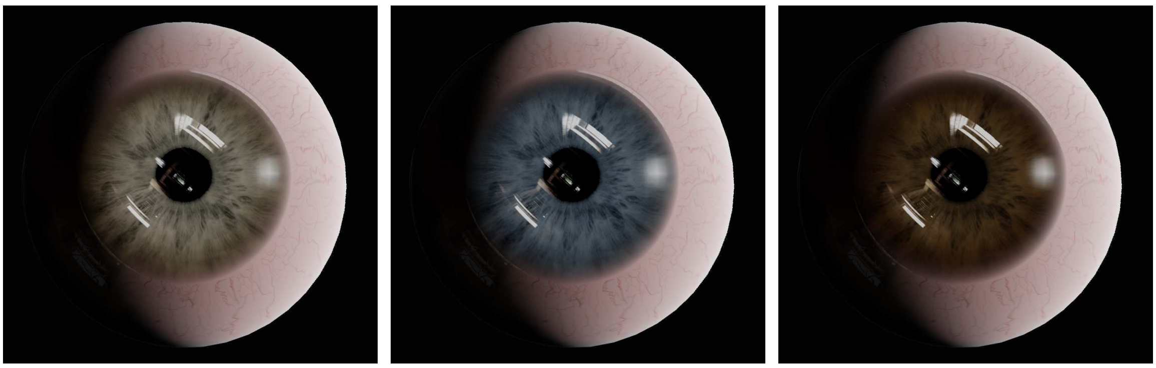


Figure 12. Green eye, Blue eye and Brown eye

The recent improvements of graphics hardware offer the opportunity of rendering complex organic materials, following correct anatomical properties. We have proposed a novel method that allows to recover the iris structure and scattering features from a single eye photograph. In this aim, we developed a method to unrefract iris photographs. We modeled the iris using the Subsurface Texture Mapping representation which allows to describe the relieves of the human iris. Finally, we introduced a refraction function for accurate real-time rendering of the eye, accounting for the refraction of the light at the corneal interface (cf figure 12).

6.7. Color human perception rendering

Participants: Kadi Bouatouch, Christian Bouville, Rémi Cozot.

Many virtual reality requires a good immersion feeling. The user position in the virtual world is related to the camera point of view. The rendered image should give a good feedback of what the user should see. In order to improve the image quality we use state of the art global illumination algorithms. But these algorithms take only physics into account. They do not take care of the human perception of colors which is described by color appearance models (CAM) in the field of color science. Our main objective is to take the CAM key features into account in the rendering engine.

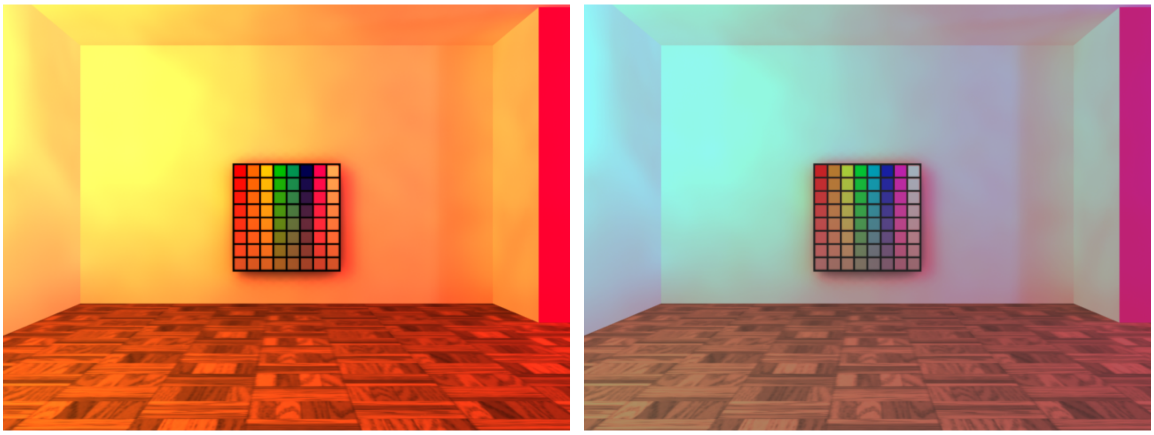


Figure 13. Global illumination image with our white balance

The chromatic adaptation also called white balance (cf figure 13) is one of these CAM key features. Even state of the art chromatic adaptation algorithms do not give good results in the case of global illumination because they make strong assumptions about the real image for white balancing purpose. Unfortunately theses assumptions are no more true for virtual images. So we propose a new chromatic adaption algorithm suitable for computer generated images provided by global illumination algorithms.

6.8. Real-time Rendering for Multiview Autostereoscopic Displays

Keywords: *Multiview*, *Rendering*, *autostereoscopic*, *display*.

Participants: Kadi Bouatouch, Bruno Mercier, Christian Bouville.

Multiview autostereoscopic displays are now available at affordable cost and are set to become widely used in virtual reality applications and 3D games. With their wide viewing zone, this type of display easily accommodates multiple viewers and no head tracking is required. However, real time rendering on these displays poses a number of difficult problems, the first one being of course the simultaneous generation of several views of the same 3D scene. Besides, the particular sampling pattern of the displayed image requires specific anti-aliasing procedures and this results in limiting the usable depth range. The purpose of our work is thus to tackle these problems. In particular, 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 multiview image with a commodity graphic hardware.

6.9. Interactions within 3D Virtual Universes

Keywords: *Collaborative Interactions*, *Collaborative Virtual Reality*, *Immersive Interactions*.

Participants: Thierry Duval [contact], Laurent Aguerreche, Benoît Chanclou, Alain Chauffaut, Anatole Lécuyer.

Our goal is to offer better interaction possibilities to end-users of 3D virtual environments. We first explore the different interaction possibilities in the fields of multi-users collaboration and multi-modal interactions, then try to provide generic tools to enable interactivity with virtual objects.

This work uses the OpenMASK environment to validate concepts, to create demonstrators, and to offer interaction solutions for all OpenMASK users.

Interaction distribution between several sites relies upon the distributed mechanisms offered by OpenMASK: referentials and mirrors.

Multi-users and multi-modal interactions use the data-flow communication paradigm supported by OpenMASK, allowing data transfer from outputs towards inputs, and facilitate the fusion of the inputs coming concurrently from several outputs. They also use the sending event communication paradigm of OpenMASK that allows to send events even to objects that are located on distant sites.

6.9.1. The Immersive Virtual Cabin (IVC)

The objective of the Immersive Virtual Cabin 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. This tool is dedicated to interaction and navigation within Multi-Scale Collaborative Virtual Environments (MSCVE). We have developped a first prototype of the IVC (see figure 14) which is a set of reusable modules within the OpenMASK Collaborative VR development framework.

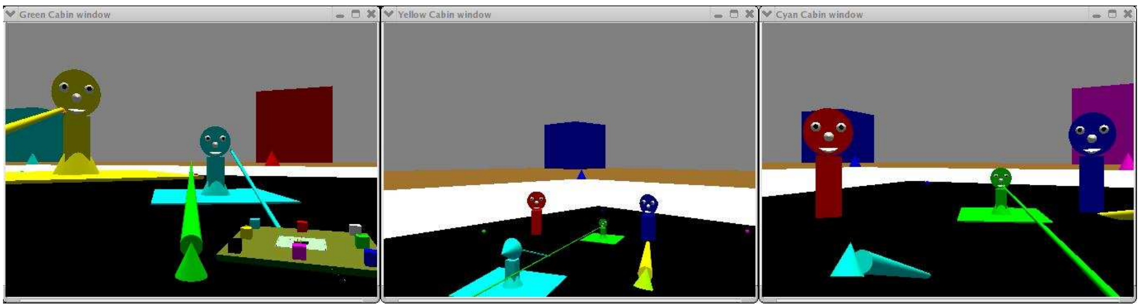


Figure 14. Three users with three IVC navigating and interacting within a MSCVE

The main goals of the IVC are to control the users' virtual workspace to allow him:

- to define his real workspace with its relations to the output devices (display of the physical limits of the IVC: the projection screens),
- to navigate within the virtual environment, whatever its size, with the richest navigation functionnalities possible,
- to change dynamically its scale, to explore various aspects of the virtual universe, at microscopic or macroscopic levels,
- to embark his virtual and real interaction tools, and to manipulate them in the user's coordinate system (the coordinate system attached to the IVC) or in other coordinate systems (the absolute coordinate system of the virtuel universe, or of the manipulated object, or of another user),
- to integrate various physical workspaces linked to the freedom of move offered by the input (colocalization of the physical input devices).

The natural activity workspace of the user is the IVC: he can move inside the IVC, but from this place he will not be able to reach every object of the universe, thus he will have to be able to move the cabin or to use long-range tools as presented in the related work. Indeed, the workspace of some tools is not limited to the virtual cabin: long-range tools like the virtual rays, the remotely handled cursors, the extensible arms, can be used if we can see beyond the limits of the IVC.

The IVC is adapted to the scale of the user, i.e. the scale of the real world: it is the only way to be able to carry out, if necessary, colocalizations between the real tools and their representation in the virtual scene. It is then necessary to immerse the IVC in the virtual universe. By modifying its scale factor, one can then easily give it the size that will enable it to fit correctly in this universe. This scale factor is a public attribute of the IVC, just as its position and its orientation. Thus, the embarked tools will also be able to inherit the scale of the IVC, and to apply it at the same time to their geometry and their position relatively to the cabin.

The IVC is an interactive object: from outside the IVC, another user can take the control of this IVC in order to help to move it or to rotate it. It thus allows another user to help finding the best position and orientation for the IVC to realize further interactions.

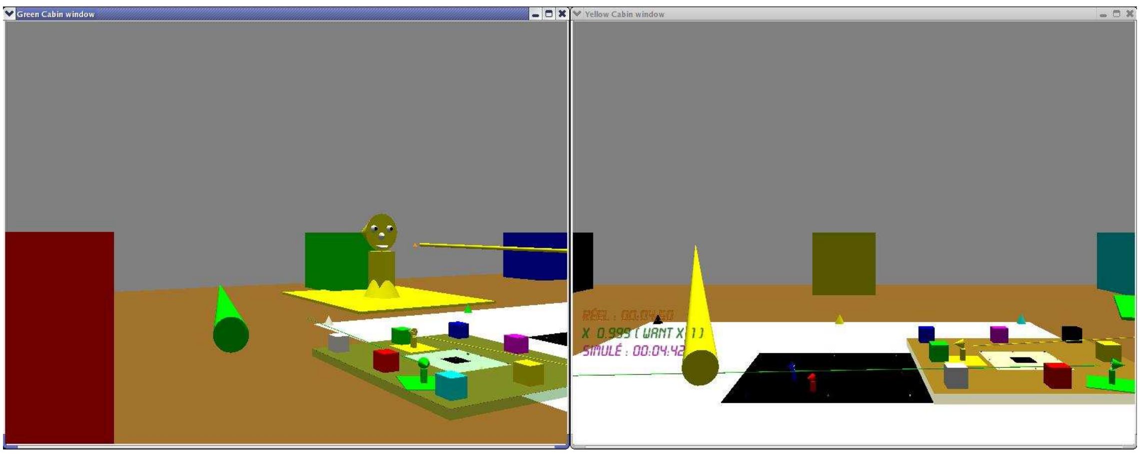


Figure 15. WIM carried by the IVCs and displayed world aligned (left window) and view aligned (right window)

The IVC can also provide a tool to make navigation easier: a carried World In Miniature. This WIM offers a visualization of the main virtual objects and of the other users of a shared virtual universe. This WIM can be displayed either world aligned as illustrated left window of figure 15, or view aligned as illustrated on the right window of figure 15.

6.9.2. Generic Interaction Tools for Collaboration

Our goal is to propose software utilities in order to help implementation of new interaction metaphors for collaborative virtual environments. These softare utilities rely on a generic interaction protocol that describes what kind of data an interaction tool needs to exchange with an interactive object in order to take control of it.

This interaction protocol must be generic enough in order to be deployed on different software integration platforms such as OpenMASK, Spin3D or Virtools.

So this year we have studied the work (scientific publications and tools) relative to 3D interactions (paradigms and metaphors) in order to propose an interaction protocol able to fit with the most commonly used 3D interactions. Then a first description of this interaction protocol has been proposed in the context of the Part@ge project (deliverable 1.4.1 [50]), and it has been implemented with OpenMASK (by us) and with the Virtools VR Pack (by one of our Part@ge partners: Clarté).

6.9.3. Interaction and navigation tools for exploration of scientific data

We also study how our IVC and our generic tools could be used in the context of exploitation of 3D visualisation of scientific data (results of scientific calculations upon physical data), in order to make it easy to navigate within virtual universes showing such results and to enable several user to share common interactions with these scientific datas. This is a collaboration with EDF in the context of another ANR Project: the SCOS Project. Figure 16 shows the kind of scientific datas that EDF provides and that we have to explore in this context.

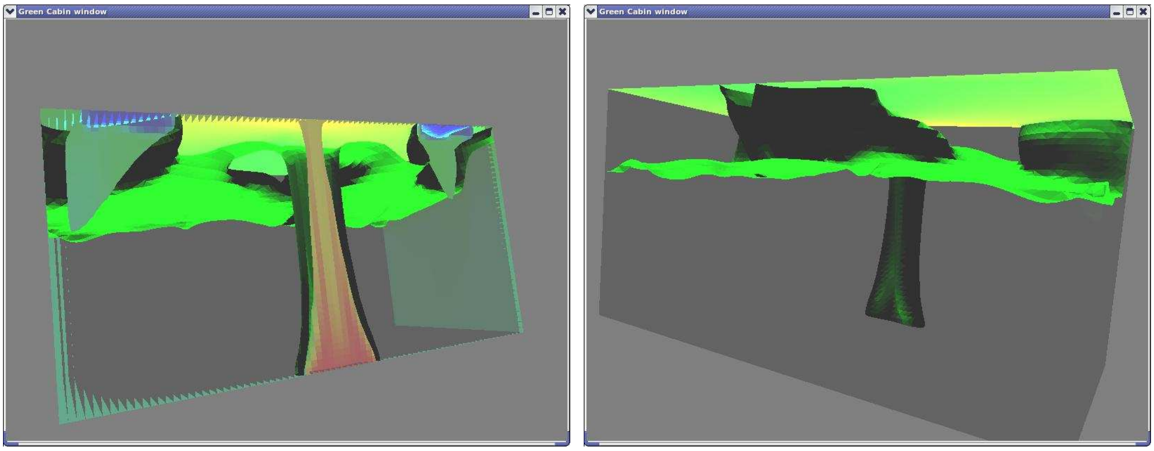


Figure 16. Two views of the exploration of results of scientific calculations with the IVC

6.9.4. Representation of 3D Cursors

Today, the avatars or 3D cursors used to display the user during manipulation tasks in VE can look very different. Indeed, the visual shape of the user's avatar can either be a tool (e.g., screwdriver, hammer), the whole or a subpart of the body (eye, hand, finger) or even any other object with or without a semantic content (arrow, star, sphere).

However, we do not know today the potential effect of the visual appearance of these avatars on the behaviour of the users, during virtual manipulation tasks. In this study, we focused our investigation on the two following questions:

1. Does the visual appearance of the avatar or 3D cursor used to display the user in the virtual environment have an effect on his/her way of manipulating the interaction device?
2. Does the visual appearance of the avatar have an effect on his/her behaviour when manipulating virtual objects?

We have conducted two experiments to investigate these two issues. We have studied the influence of the directional cue of the avatar used to display the user in the virtual environment during a selection and manipulation task (see Figure 17). The results of a first experiment showed that the visual orientation of the avatar influenced the way participants manipulated the real interaction device. The participants changed the orientation of their hand as function of the orientation suggested visually by the shape of the 3D cursor. The second experiment showed that the directional cue of an avatar could change the way participants selected and picked up a virtual cube. The visual directional cue of arrows or virtual hands could make the participants pick up the virtual cube by its right or left sides. Other cursors (with no main directional cue) led the participants to pick up the cube by its front or top.

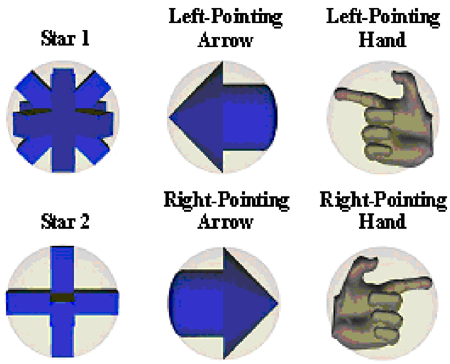


Figure 17. Avatars used in Experiment 2

Our results suggest that the choice of the graphical display of the user's avatar or 3D cursor is very important in virtual manipulation tasks. Indeed, the visual directional cue of an avatar can partially determine the manipulation strategy in the VE. It could support or impair the user when he/she manipulates virtual objects and interaction devices. Such effect could be used to favour optimal uses of manipulation interfaces in virtual environments, such as with haptic devices with limited rotational workspace.

This work was published at the IEEE symposium on 3D User Interfaces 2007 [35]. It was achieved as an external collaboration with P&I Lab, University of Angers/ENSAM.

6.10. Improvement of immersion feeling in virtual reality

Participants: Rémi Cozot, Sébastien Hillaire, Anatole Lécuyer [contact].

Virtual reality needs real-time rendering. But the virtual images may sometimes look "too synthetic" or "too perfect" and provide a weak immersion feeling. We carry out experiments to improve the immersion feeling. Our first work focus on taking into account human vision features in real-time rendering.

Depth-of-field (DoF) of the human's eyes is the range of distances near the point of focus where the eyes perceive the image as sharp. Objects behind and in front of the point of focus are blurred. DoF and its associated blur effects are well-known and classical depth cues in human vision . According to this, we study the use of visual blur effects, i.e., blurring of parts of the image fed back to the user, for First-Person-Navigations in Virtual Environments (VE).

We propose a model of dynamic visual blur for VE which is based on two types of blur effect:

- a Depth-of-Field blur (DoF blur) which simulates the blurring of objects located in front or back of the focus point of the eyes,
- a peripheral blur which simulates the blurring of objects located at the periphery of the field of vision.

We also improve real-time DoF algoritm with a paradigm to compute automatically the focal distance and a temporal filtering that simulates the accommodation phenomenon.

The results of a pilot experiment conducted to study the influence of blur effects on the performance and preference of video gamers during multiplayer sessions show that visual blur effects did not degrade performance of gamers and they were preferred and selected by nearly half of the participants to improve fun and game-play. Taken together, our results suggest that the use of visual blur effects could thus be suitable in videogames and in other virtual environments.

Figure 18. Virtual environment with real-time blur effects

6.11. Haptic Interaction

Keywords: *6 DOF Simulation*, *Contact*, *Event-Based*, *Haptic*, *Haptic Hybrid Control*.

Participants: Anatole Lécuyer, Bruno Arnaldi, Jean Sreng.

Haptic interaction consists in providing the user of a Virtual Reality system with the sensations involved by touch during the manipulation of virtual objects, i.e., tactile and force feedback. We describe hereafter our recent results in the field of haptic interaction which concern: (1) interaction techniques with haptics (the Haptic Hybrid Control), and (2) the use of haptic and multi-sensory feedback to display 6 DOF contact information using an event-based approach.

Haptic interaction consists in providing the user of a Virtual Reality system with the sensations involved by touch (i.e. tactile and force feedback), mainly during the manipulation of virtual objects. Historically, the development of haptic interfaces originates from tele-operation. The first force-feedback interfaces were developed for tele-operations within hazardous environments. But nowadays, a larger number of applications has been foreseen for haptic interaction in Virtual Reality. These applications belong to various fields: Medicine (chirurgical simulators, rehabilitation), Education (display of physical or mathematical phenomena), Industry (virtual prototyping, training, maintenance simulations), Entertainment (video games, theme parks), Arts and Creation (virtual sculpture, virtual instruments), etc. Thus, the field of "haptics" concerns an increasing number of researchers and companies specialized in Virtual Reality.

The integration of haptic feedback within a virtual environment raises many problems at different levels, including the hardware and software issues. Furthermore, a current major limitation for the design of haptic interfaces is the relatively poor knowledge concerning human haptic perception. It is indeed fundamental to take into account the psychological and physiological issues of haptic perception when designing the technology and when defining the use of virtual environments based on haptics. We therefore concentrated our work on both the perception issues and the implementation issues. Our recent results in the field of haptic interaction in virtual reality concern:

1. **the Haptic Hybrid Control**: a novel interaction paradigm for object manipulations in large VE using haptic devices with limited workspace
2. **Rendering of Contact Information**: a set of haptic and multi-sensory cues that display contact information in 6 DOF simulation using event-based approach.

6.11.1. The Haptic Hybrid Control

Haptic devices allow manipulation and interaction only inside their limited physical workspace. Therefore, the user can not reach and interact with virtual objects located outside this workspace easily.

The "Bubble" technique is a novel interaction technique to interact with large Virtual Environments (VE) using a haptic device with a limited workspace. It is based on a hybrid position/rate control which enables both accurate interaction and coarse positioning in a large VE (see Figure 19). The haptic workspace is displayed visually using a semi-transparent sphere (looking like a bubble) that surrounds the manipulated cursor. When the cursor is located inside the bubble, its motion is position-controlled. When the cursor is outside, it is rate-controlled. The user may also "feel" the inner surface of the bubble, since the spherical workspace is "haptically" displayed by applying an elastic force-feedback when crossing the surface of the bubble.

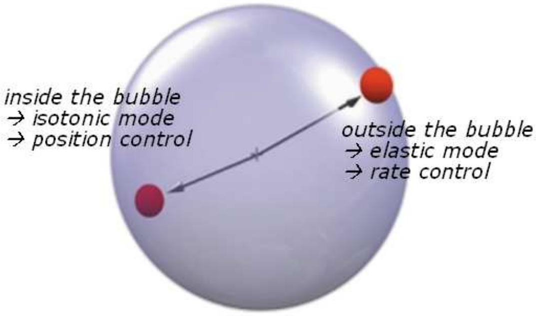


Figure 19. Concept of the Bubble technique

We have also developped another interaction technique called Haptic Hybrid Rotations aiming at overcoming the physical angular limitations of force-feedback devices when manipulating virtual objects in rotation. This technique is also based on a hybrid control of the object manipulated with the device. When approaching the angular mechanical stops of the device, the control mode switches again from angular position-control to rate-control. The force-feedback of the device is used to simulate the use of an elastic device in the rate-control mode. Regarding the roll component, we chose to bind this degree of freedom with two imaginary angular springs constraining the device between two given orientations (see Figure 20). When the device operates between these two angular springs, the roll of the manipulated object is position-controlled; beyond the springs, it is rate-controlled. Regarding yaw and pitch, the space contained between the mechanical stops would be bounded by a prismatic conic-like shape. For simplification and usability purpose, we chose to approximate this shape to a cone. When the device operates inside the cone, yaw and pitch are position-controlled; outside the cone, they are rate-controlled. We propose to display the cone and the roll angular springs both haptically and visually. This choice was made to ensure a consistency between the visual and haptic spaces. In addition to the haptic display, the cone and the roll limits are displayed visually as well. An avatar of the device is also displayed to provide the user with hints regarding its orientation.

These two techniques are both inspired by the same concept of Haptic Hybrid Control (HHC) [14]. The HHC promotes a hybrid position and rate control, coupled with the simulation of the behaviour of an elastic device during the rate control phases. It aims at enhancing the versatility of human-scale devices by allowing the user to overcome their physical limitations. The definition of Haptic Hybrid Control, its main parameters and its combination with human-scale haptic devices was discussed and published this year in Visual Computer journal [14]. This work was achieved as an external collaboration with CPNI Lab., University of Angers.

6.11.2. Event based rendering of contact

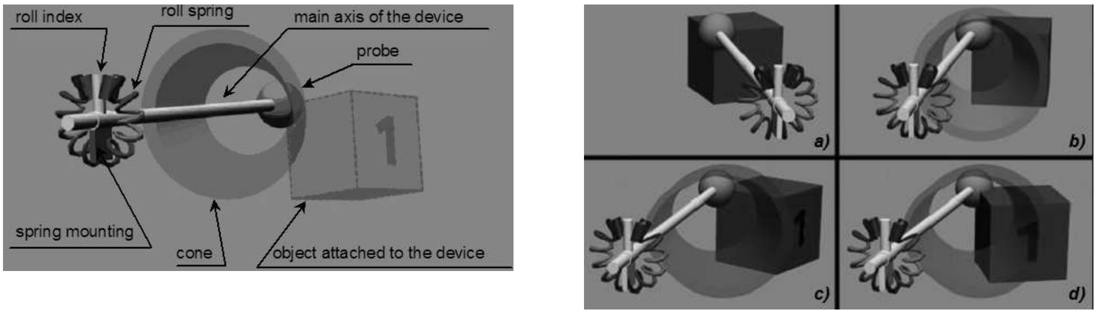


Figure 20. The Haptic Hybrid Rotations technique

The notion of contact is a main feature of physical simulation of solid objects as the contact constrains one objects movement with respect to its environment. A good perception of contact is a main requirement for an improved user experience. However, due to the growing complexity of simulated virtual scenes and limited computational resources, realistic haptic and audio real-time rendering of contact cannot be efficiently achieved by the physical simulation.

Therefore, we proposed a general event-based approach to improve multimodal rendering of 6DOF contact between objects in interactive virtual object simulations.

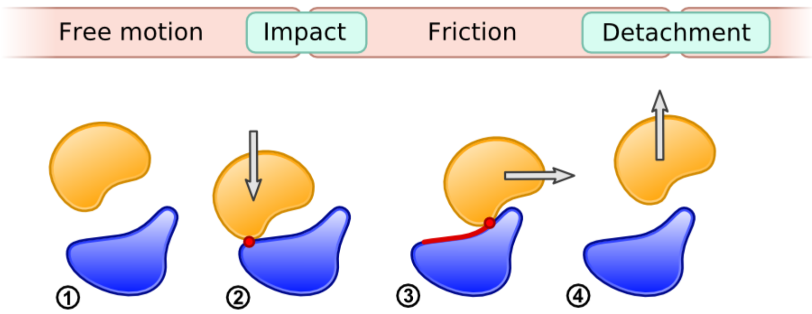


Figure 21. Contact states

The contact events represent the different steps of two objects colliding with each other : (1) the state of free motion, (2) the impact event at the moment of collision (3) the friction state during the contact and (4) the detachment event at the end of the contact (see Figure 21).

The different events are used to improve the classical feedback by superimposing specific rendering techniques based on these events. First we proposed a general method to generate these events based only on the objects' positions given by the simulation. Second, we developed a set of different types of multimodal feedback associated to the different events that we implemented in a complex virtual simulation dedicated to virtual assembly. We proposed a visual rendering of impact, friction and detachment based on particle effects (see Figure 22). We used the impact event to improve the 6DOF haptic rendering by superimposing a high frequency force pattern to the classical force feedback. We also implemented a realistic audio rendering using impact and friction sound on the corresponding events.

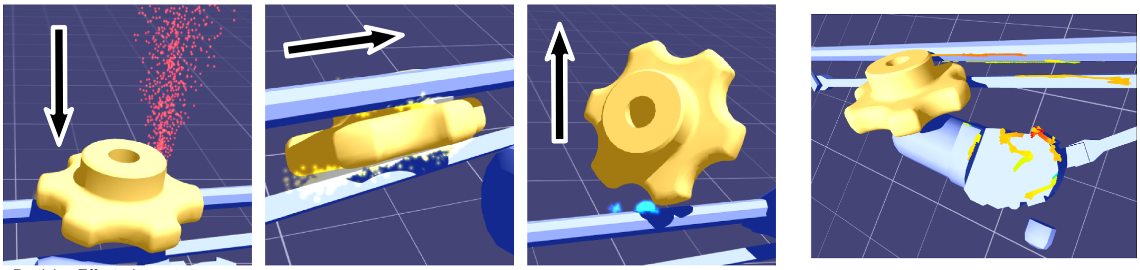


Figure 22. Visual display of contact states and contact events

This work was published at the ACM Virtual Reality Software and Technology 2007 [46]. It was achieved as an external collaboration with CEA LIST.

6.12. Brain-Computer Interaction in Virtual Reality

Keywords: *Brain-Computer Interface*, *Classification*, *EEG*, *Fuzzy Inference System*, *Inverse Model*, *Neuro-feedback*, *Real-Time*, *Spatial Filter*, *Visualization*.

Participants: Anatole Lécuyer [contact], Fabien Lotte, Yann Renard, Fabrice Lamarche, Vincent Delannoy, Bruno Arnaldi.

6.12.1. A Review of Classification Algorithms for EEG-based Brain-Computer Interfaces

We realise an important bibliographic work with the aim of proposing a review of classification algorithms used to design Brain-Computer Interface systems based on EEG. We reviewed the commonly employed algorithms and their critical properties. Then, based on the literature, we compared them in terms of performance and conceived guidelines to choose the suitable classification algorithm(s) for a specific BCI. This work has been accepted and published in *journal of neural engineering* [20]. In May, this article had been downloaded more than 500 times. To put this into context, across all IOP journals, only 3% of articles were accessed over 500 times this year, showing the need of such a state-of-the-art on classification methods for EEG-based BCI.

6.12.2. A Study of the Use of Fuzzy Inference Systems for Motor Imagery Classification

We continue studying Fuzzy Inference Systems (FIS) for classification in EEG-based BCI. FIS are fuzzy classifiers that are composed of a set of fuzzy “if-then” rules, that can be automatically learnt from data. We studied their use for motor imagery classification. The results of the four studies we achieved were promising as, on the analysed data, the used FIS was efficient, interpretable (see Fig. 23), showed good capabilities of rejecting outliers and offered the possibility of using *a priori* knowledge, expressed under the form of hand-made fuzzy rules. This work has been accepted and published in *IEEE transactions on neural systems and rehabilitation engineering* [21].

6.12.3. FuRIA: A Novel Feature Extraction Algorithm for Brain-Computer Interfaces using Inverse Models and Fuzzy Regions of Interest

In this work, we proposed a new feature extraction algorithm for Brain-Computer Interfaces (BCIs). This algorithm is based on inverse models and uses the novel concept of fuzzy Region Of Interest (ROI). It can automatically identify the relevant ROIs and their reactive frequency bands (see Fig. 24). The activity in these ROIs can be used as features for any classifier.

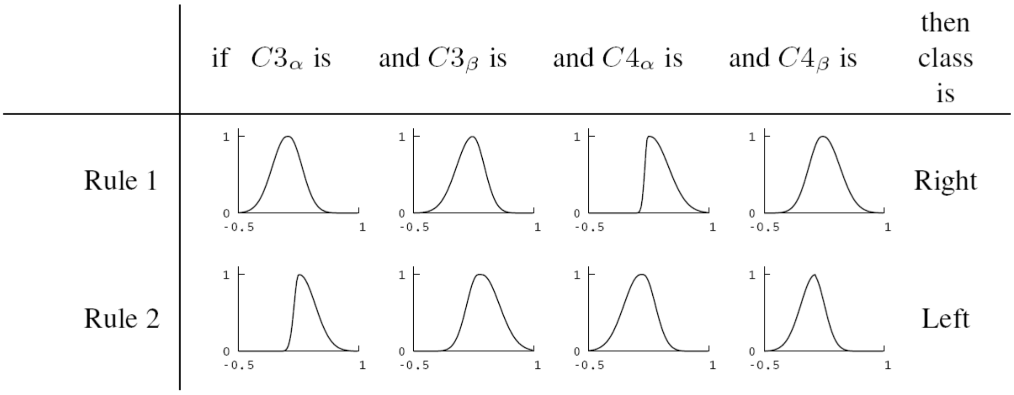


Figure 23. Fuzzy rules automatically extracted by the FIS from the EEG of a subject who was performing mental imagery of left and right hand movements. The features used (i.e., $C3_\alpha$, $C3_\beta$, $C4_\alpha$ and $C4_\beta$) correspond to the power of the EEG signals, recorded over the electrodes C3 and C4, in the frequency bands α (≈ 8-13 Hz) and β (≈ 16-24 Hz)

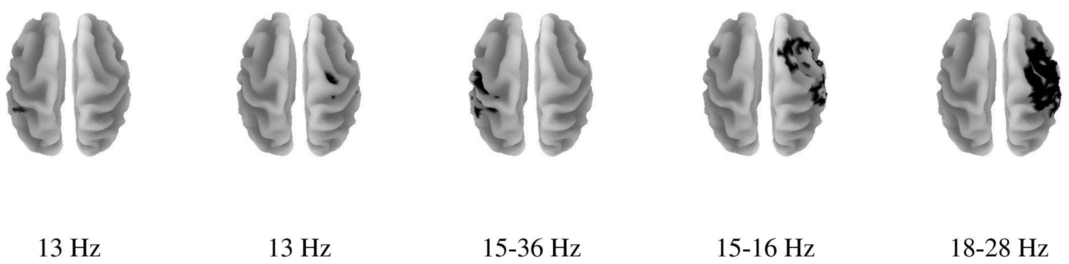


Figure 24. The fuzzy ROI (in black) and their corresponding frequencies that were automatically obtained by using FuRIA. The brain is inflated and is seen from the top, front up.

A first evaluation of the algorithm, using a Support Vector Machine (SVM) as classifier, has been achieved on data set IV from BCI competition 2003. Results are promising as we reached an accuracy on the test set ranging from 85% to 86% whereas the winner of the competition on this data set reached 84%. This work has been published and presented at the national *conference GRETSI* [36] as well as at the *international IEEE-EMBS conference on neural engineering* [37].

All these works were also published and presented in an invited paper, at the national conference *Les Journées Nationales de la Recherche en Robotique* [38].

6.13. Virtual reality to analyze interaction between humans

Keywords: *Human Motion*, *Motion Understanding*, *Virtual Reality*.

Participants: Franck Multon, Richard Kulpa, 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. However, the main problem is: how to ensure that people behave as in real world when they are immersed in a simulated environment?

In the past, in collaboration with M2S (University Rennes2), 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 that objective was to intercept the corresponding virtual balls. The main advantage of this situation is that the goalkeeper has to anticipate the trajectory of the ball according to the opponent's gestures otherwise it could not have enough time to intercept the ball. In our previous work, we demonstrated that goalkeepers react the same way to real and simulated throws. We also demonstrated that the goalkeeper's gestures were affected be changes applied to the thrower's motions [1].

In order to better identify the parameters that affects the goalkeeper's decision, we decided to analyze the effect of graphics quality on the decision-making process of the goalkeeper. We carried-out this work in collaboration with M2S of University Rennes2 and Queen's University of Belfast. Several simplifications are made when animating virtual opponents in VR. These simplifications may have an impact on the goalkeeper's perception and should be identified, preliminary to other studies. We thus asked goalkeepers to predict the virtual ball trajectory for a set of throws animated with 4 different geometric levels of details: normal texture, uniform-texture (black color on the whole body), line segments instead of polygons and a point-light display (with black spots on the joints' centers) (see figure 25).

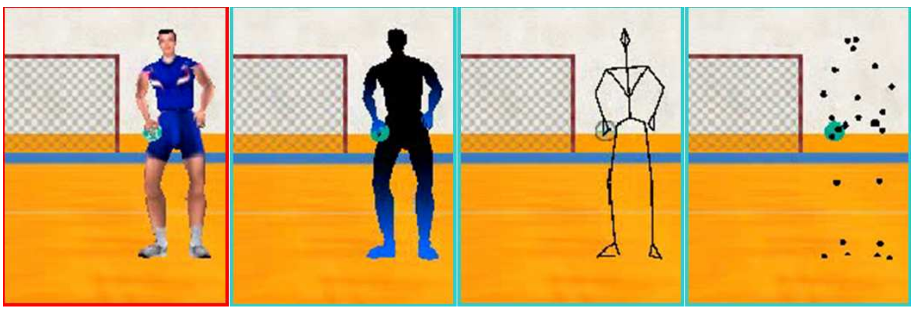


Figure 25. Four levels of detail for animating virtual throwers in VR.

For each situation and each throw, the goalkeepers was asked to predict the area in which the ball was supposed to enter the goal. We then compared the error of the user for each level of detail. The results demonstrate no statistical difference between the different levels of details. This result is in accordance with the literature in psychology of perception (Johansson 1973) that demonstrated that point-light display provides enough information to recognize motions. However, it also tends to demonstrate that the protocol involving animation of virtual humans can be used for studying the natural interaction with real users. Indeed, the graphics quality used in this work seems to have no real influence on the subjects' anticipation skills.

In the future, this work should be extended in two main directions. First, we wish to animate teams of players that implies being able to control the behavior of each autonomous player. This is a challenging task because the behavior of such teams is really complex and not still well understood. Second, we wish to extend this work to other sports where new scientific problems occur. For example, in tennis or football, the goalkeeper has enough time to take some information on the ball trajectory, contrary to handball. This work will continue to involve specialists in sports sciences (M2S of University Rennes 2) and neuroscientists (UMR 6152 "Mouvement et Perception" in Marseille and Queen's University of Belfast).

6.14. Dynamics in humanoid motions

Keywords: *Dynamics*, *Human Motion*, *Motion Adaptation*, *Real-Time simulation*.

Participants: Franck Multon, Richard Kulpa, Ludovic Hoyet.

Motion capture is now widely used to animate human-like figures while it requires post-processing in order to adapt the trajectories to various skeletons and environments. In many applications, it is also possible to combine several motions in order to perform complex tasks. However usually the physical correctness of the motions is affected and, as a result, the final animations look unnatural.

An interesting case study is gymnastic motions which are mainly affected by dynamics: during aerial motions, the angular momentum is constant and the trajectory of the center of mass (COM) is perfectly defined. Although these dynamic constraints are very restrictive (no possible additional forces), gymnasts are able to initiate twists in the air (named the cat landing problem) and to control their angular velocity. In that case, kinematic models fail to reproduce such kind of behavior accurately .

Models dealing with dynamics are generally based on specific controller design or optimization. The former leads to long hand-tuning for each new situation while the latter generally requires lots of computation time. The idea of controlling simpler interactive dynamic constraints instead of driving joint torques has also been explored without using optimization. Our method falls into this category. We thus focus on the aerial phase but we control both linear and angular momentum.

The main idea here is to solve the dynamic constraints at each time step because the interactive environment may change due to the action of a user (for example his arms' motion are added to the current animation in real-time).

The overall process is depicted in figure 26. A user selects a motion capture file among a database of aerial motions. Then, he chooses a virtual human. Before running the simulation, the user can also provide an initial velocity vector at take-off that is different from the original one.

During the animation, the gestures of the subject are captured with a real-time motion capture system. Hence, his arms gestures can be added to the original motion in order to see the consequence on the resulting somersaults and twists. The animation engine takes the following steps:

- motion retargeting (in order to adapt the motion to the skeleton) and blending (to add the subject's motions to the current pose at each time step). Motion retargeting is performed using the method proposed in [4].
- COM dynamics module that computes the initial angular momentum L_0 (constant for each time step) and the physically-valid trajectory of the COM. The angular momentum is calculated using the two first time steps after take-off:

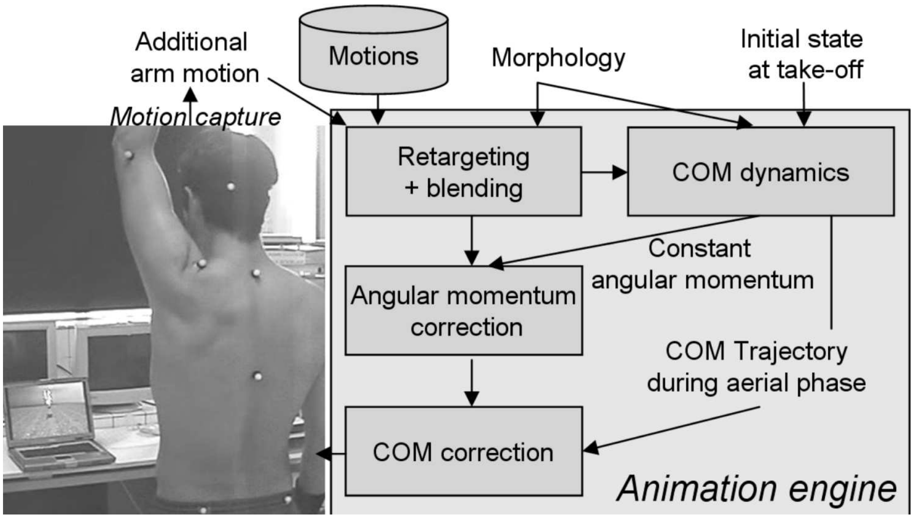


Figure 26. Real-time interaction between a user and a virtual gymnast to create physically-valid aerial figures.

$$L_0 = \sum_{i=1}^{n} I_i \omega_i + m_i GG_i \times \dot{GG_i}$$

where n is the number of body segments, m_i, I_i and ω_i are the mass, inertia and angular velocity of the COM of segment i, denoted by G_i.

- Angular momentum correction adapts the motion provided by the retargeting and blending module in order to ensure that the angular momentum is equal to L_0.
- COM correction adapts the whole-body translation in order to follow the trajectory computed with the COM dynamics module.

Some results are presented in figure 27 for different arm adaptations.

This work has been carried-out in collaboration with Taku Komura from University of Edinburgh.

One of the most important perspective consists in taking the user's whole-body motion into account instead of only using the arms. A limitation of our current work is about take-off and landing. When contact with the ground occur, he motion is not modified which could lead to unrealistic accelerations. We are currently working on a method to deal with the connection between the contact and the aerial phases. It could consist in coupling motion warping and a search into a database of possible reactions at landing.

6.15. TopoPlan: a topological planner for $2D^{1/2} - 3D$ environments

Participant: Fabrice Lamarche [contact].

Navigation inside virtual environments has a key role in behavioural animation as it is part of a large number of behaviours. Most often, virtual environments are furnished as 3D databases modelled by 3D designers. Populating such environments requires to compute data structures, based on the environment geometry, enabling path planning and obstacle avoidance for virtual human navigation. The challenge is then to plan a path and adapt the humanoid motion to the environmental constraints in real time.

Figure 27. Somersault composed with a) fast right-arm motion => important twist, b) late/slow left-arm motion => negligible twist c) fast two-arms motion => no twist. The green character plays the original motion while the normally-textured one is adapted to satisfy the mechanical laws.

(a) (b)

Figure 28. Real time motion adaptation computed thanks to TopoPlan

TopoPlan is a model enabling real time path planning inside complex environments. It is able to analyse a 3D database in order to automatically extract an informed topology. It relies on a 3D extract subdivision enabling the computation of accurate spatial relation between cells. Starting from those spatial relations, the model automatically extracts a topological representation of the environment. A topological representation relies on the computation of continuous surfaces (named zones) compounded of cells having similar properties (those properties are user defined and can relate to geometrical properties and / or semantic ones). Once zones are computed, their relations are identified and used to compute the final topology. The system is then able to automatically characterize continuous surfaces, stairs (even spiral stairs), steps...Moreover it computes bottlenecks on flat or uneven surfaces. Finally, thanks to the 3D subdivision, ceiling is also identified. Once the subdivision and its topology are extracted, they can be used in real-time to compute paths inside complex environments.

This model has been connected to MKM in order to animate a virtual human. Thanks to TopoPlan, a virtual human can plan a path inside a complex environment and adapt its motion to the ceiling geometry and the floor constraints. An example of such properties is to climb a spiral stair step by step while avoiding a beam (Cf. fig. 28 (a)). Moreover, by coupling MKM properties and TopoPlan model, the adaptation to ceiling geometry is handled thanks to a separate reactive process which automatically adapts the motions to the human morphology and ceiling constraints (Cf. fig. 28 (b)) in real time.

6.16. Locomotion model

Participants: Fabrice Lamarche [contact], Richard Kulpa [contact], Nicolas Chaverou.

Coupling reactive navigation systems with virtual human animation in order to produce high quality animations is a hard task. The goal of reactive navigation systems is to compute a speed which is a compromise between an expected speed (a speed driving a pedestrian to its goal) and obstacle avoidance (dynamic obstacles such as pedestrians and static obstacles i.e. the environment). Such systems continuously adapt the pedestrian speed in order to take into account the environment dynamics. When connecting such systems to virtual human animation, the user needs a system offering a high level interface compatible with reactive systems and generating an accurate movement (conforming to his command) as well as a realistic animation. Our locomotion model tends to fulfil those goals.

In order to generate credible locomotion animations our system analyses several recorded motions (forward, backward, left, right, running) in order to automatically extract pertinent characteristics. Those motions are then compiled into an optimized movement database. This database is used in real time in order to generate a credible movement corresponding to the user query. This query is compounded of four simple parameters easily generated by a reactive navigation model: speed, moving direction, body orientation and step length. The first property is that the system automatically generates a credible and accurate animation corresponding to the high level user query. Secondly, thanks to the movement database, a user can record new motions, compile the database and obtain a better motions without modifying its application.

An example of generated movement is presented fig. 29. This example shows a virtual human following a curve trajectory while facing the camera. Automatically, the locomotion model chooses the most adapted animations corresponding to the navigation parameters by smoothly combining forward, lateral and backward motions in accordance with the dynamically changing parameters generated by the reactive navigation model.

6.17. Reactive Navigation in Crowd Simulation

Participants: Julien Pettré [contact], Stéphane Donikian.

Main objective of crowd simulation is to reproduce in a realistic manner humans' activity within a given digital environment. One major activity of virtual humans is to execute navigation tasks. When navigating, virtual humans have to reach given destinations while avoiding obstacles. Two different kind of obstacles are to be distinguished: static (such as walls) or dynamic (moving objects or other virtual humans). Navigation planners are able to provide a global solution path toward a desired destination while taking into account the position of static obstacles. When virtual humans follow a global solution path, they also have to take into

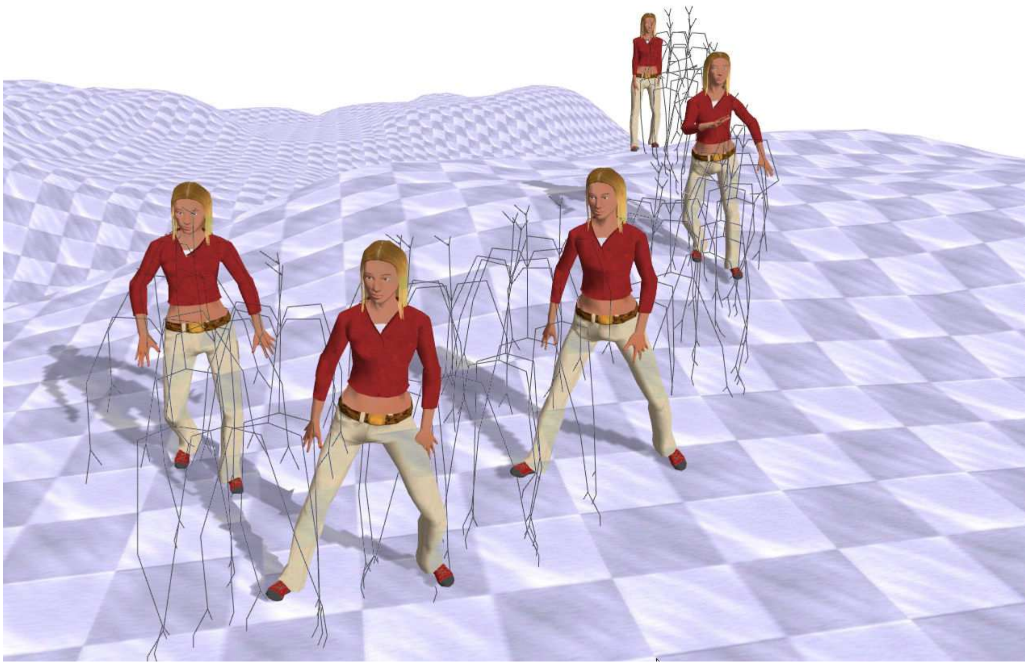


Figure 29. Example of a generated animation

account the presence of dynamic obstacles on their way. Such interactions are solved in a reactive navigation step.

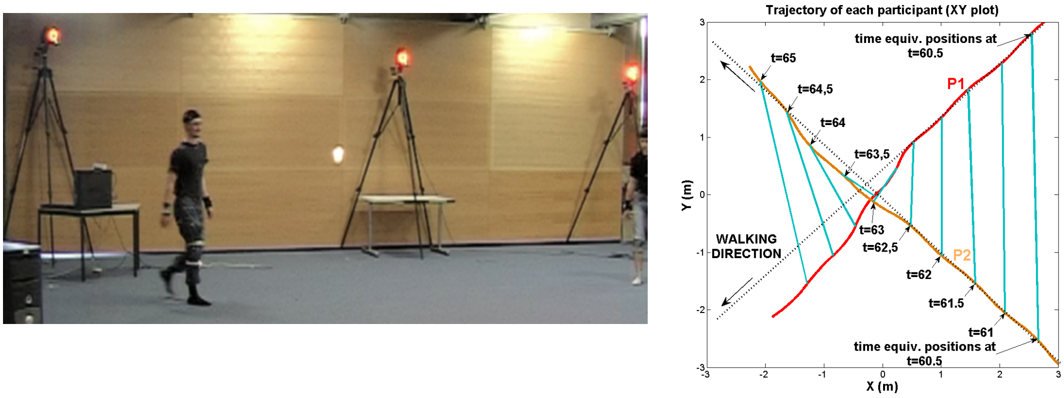


Figure 30. Experiments for analyzing the interaction of two participants

The level of realism of reactive navigation process is crucial to simulate correctly the circulation of pedestrians. As a result, we performed experiments in order to observe real humans during interactions (here, *interaction* means the reaction of pedestrians having intersecting trajectories); using adequate protocols, we constrain the motion of real humans in order to provoke interactions between them. We can finally observe each participant's strategy to avoid a collision with the other, consisting of velocity changes or lateral deviations. Figure 30 illustrates the experimental setup (left picture) as well as an example of measured trajectories. From the analysis of experimental data, we are able to calibrate the reactive navigation module of our crowd simulation architecture.

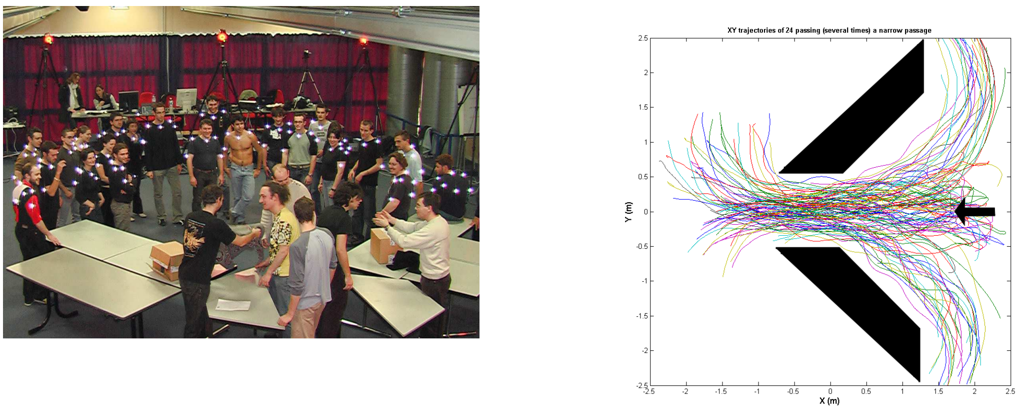


Figure 31. Experiments on navigation of groups among obstacle: experimental setup and measured data

We also studied the motion of a group of real humans navigating among obstacles. From these experiments, we obtain local statistical data on humans' navigation within a crowd such as: average navigation velocities, accelerations or deviations in function of the obstacles, but also size and shape of obstacle-free personal space around each participants (also known as the *Goffman's oval security area*). The objective of acquiring such data is to allow model validation from comparison between experimental data and simulation results. The validation problem is known to be of importance and difficult in practice. Figure 31 illustrates our experimental setup (left image) and an example of measured data (right image).

6.18. Crowd simulation inside exchange areas, with levels of services characterisation.

Participants: Sébastien Paris, Stéphane Donikian [contact].

Crowd simulation is an emergent problem nowadays, because of a growing interest on behalf of industries and certain organisations. Many studies have been performed, mostly using macroscopic models, or *light* microscopic ones (like particle based). We propose in our model to simulate the emergent crowd behaviour by association of a multitude of individual behaviours, and to extract realistic enough data to allow further exploitation.

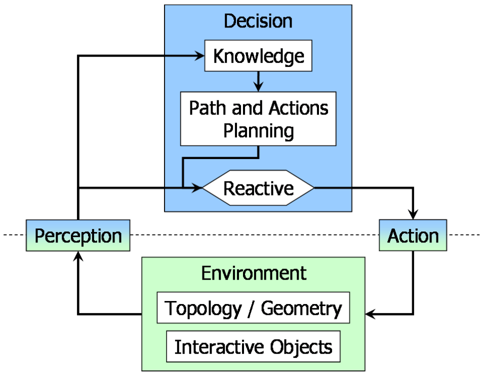
This study is carried out within the framework of an industrial thesis in collaboration with AREP, *Aménagement Recherche pour les Pôles d'Echange*, which is a subsidiary company of the SNCF, *Société Nationale de Chemins de Fer*. This collaboration between AREP, SNCF, and Bunraku is continued by the ANR project called SIMULEM. This project has for objective to validate the models proposed by Sébastien Paris' PhD [10], and to operate them in a simulation tool also called SIMULEM. The goal of this study is to validate train station architectural plans with respect to the movements of people. The validation must take into account flows of people inside the environment, but also the way the entities can easily perform their tasks or locate things in the places.

Our model [10] is based on the well known *perception – decision – action* loop (*Fig. 32*). In this model, the environment is described in two parts: first, its topology and geometry correspond to the architectural plan; second, the interactive objects allow to situate the interaction. Then, autonomous agents are able to perceive the environment, to take a behavioural decision based on this perception and an individual knowledge, and finally to perform some actions which will impact the environment.

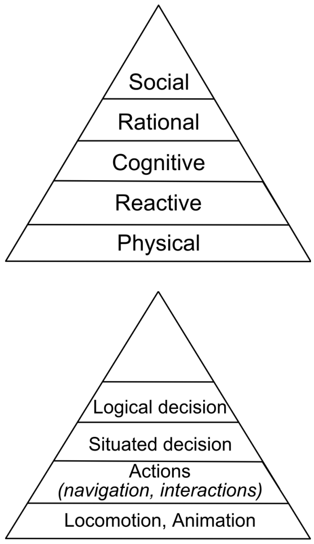
We use a multi-layer approach for the decision model of the autonomous agent (*Fig. 32*).
The rational layer is represented by a logical decision process allowing goal oriented behaviours. This process is based on concepts related to interaction, unified in an architecture called BIIO (Behavioural Interactive and Introspective Objects). At the heart of the logical decision process is the concept of affordance, which represents an interaction with five components:

1. A rational precondition, which is a boolean expression relative to the actor and the type of object to interact with.
2. A local precondition, which is a boolean expression relative to the actor and the selected instance of object to interact with.
3. A control process during the interaction, which might affect both of the actor and the object to represent the evolution of the interaction.
4. A validation process, which applies the consequences of the interaction.
5. A duration, which defines the the total time to perform the interaction.

The cognitive layer of the agent is in charge of the situated decision, taking into account time and space to select the interaction to perform. This layer is based on a novel approach using path planning for action selection.



(a) Overview of the micro-simulation model based on the *perception – decision – action* loop.



(b) The decision pyramid of the virtual human. On the top, the original Newell's description. On the bottom, the equivalent pyramid in our multilayer model.

Figure 32. Overview of our models for multi-agents crowd simulation.

The reactive layer represents more physical behaviours, with perception and the reactive navigation. We have proposed a novel approach for reactive navigation [26], based on the anticipation of the movement of people. This model produces realistic results either for high or low densities of people, and allows to manage both repulsive and attractive neighbours.
The physical layer manages automatic behaviours for human beings, and is represented by the MKM animation model in our approach.

We finally obtain a fully autonomous agent model, which is directly driven by high level goals. For example, an outgoing passenger in a train station will have to take the train (as final goal), which implies for him to perform some sub-tasks representing the needs to take the train (*Fig. 33*): buy a ticket, check the departure board, or punch the ticket.

6.19. Collaboration between real users and virtual humans in a virtual environment for training

Participants: Bruno Arnaldi, Stéphanie Gerbaud.

The actual release of GVT, presented in section 5.5, allows a single trainee to learn an individual procedure. Our work consists now in enhancing GVT by allowing trainees to train on a collaborative procedure with other real users or/and with virtual humans. The modifications needed have been presented in [32] and a prototype has been developped.

6.19.1. A model of the humanoid activity

We model a virtual human and the avatar of a real user the same way, thanks to what we call the humanoid model. STORM is a model of behavioral objects and also a model of interactions between these objects. A humanoid is then a STORM object so that he can interact with other STORM objects, including other humanoids. The humanoid manages inner ressources, such as his two hands which are also STORM objects

Figure 33. Example of the goal oriented behaviour of an outgoing passenger.

able to interact. The global humanoid is also able to enter in interaction in its globality, for example to establish a communication link. The modeling of a humanoid with STORM as well as the global STORM model have been presented in [40].

6.19.2. A collaborative scenario

The LORA langage was designed to express a complex sequence of interactions which is the referential procedure for a single student in the training environment. We made this language evolve in order to describe collaborative procedures with multiple trainees. For each scenario action we add a role field which indicates the roles allowed and their priority. We have thus decided to allow several roles for one scenario action. This innovation leads to a flexible repartition of the actions between the actors while keeping the strict scheduling of these actions. The procedure is then more adaptive to a different context (number of people, location of each person and his availability, etc). Nevertheless, in return, it imposes to the set up a specific mechanism able to suggest who is the best candidate for each scenario action.

We have also decided to simplify the writing of procedures, in order to improve scenarios flexibility and to increase productivity. Thus, we allow to omit in the scenario common actions like to take and to put back objects, which gets closer to the real specification of maintenance procedures. Instead, we add for the other actions pre and post conditions on the actor's state of the hands.

6.19.3. A mecanism of action selection

We set up a mecanism able to suggest, for each scenario action, the best candidate from the scenario point of view. Based on that, virtual humans can select the next action to do, and advices can be made for real users about what action to choose and why. Therefore this mecanism is divided into two modules. The first one is a repartition module, the aim of which is to make a global repartition of the actions among the humanoids, respecting the scenario requirements. This module, taking into acount various criteria, classes the different candidates for each scenario action, depending on their abilities to make the procedure progress. The module of action repartition makes a global repartition of the actions among the humanoids, respecting the scenario requirements. But it is only a propositional repartition and it is up to each virtual human to make an individual choice thanks to his own decision module. Therefore, the second module is a decisional module, local to each humanoid, which selects the action to perform, respecting rules that composed his pedagogical profile. By selecting different rules, we can create a virtual human who tends to help the other actors, who only performs the actions he is supposed to, etc. The module of repartition (centralized) combined with the decision modules of every virtual human (local) form the whole process of "action selection". This mechanism leads to interesting properties: increased flexibility in the repartition of the tasks, possibility to design or perfect procedures by observing virtual humans who realize the procedure, possible emergence of implicit collaboration such as a virtual human who helps a real user performing his task if he is blocked.

7. Contracts and Grants with Industry

7.1. Nexter: Virtual Training

Participants: Bruno Arnaldi, Nicolas Mollet, Xavier Larrodé, Stéphanie Gerbaud.

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. GVT is based on OpenMASK, the VR-platform of the Bunraku team (INRIA), and AReVi (ENIB-Li2 VR-platform). All of our developments are totally re-usable in industrial training, and are not dedicated to a particular industrial equipment and procedure. We focus our activity into the following points:

- design of true reactive 3D objects (including complex objects such as a virtual human) with embedded behaviors: the STORM model.

- design of high level specification language, LORA, in order to describe complex and potentiallly collaborative human activity (virtual activity in relationship with the real activity).
- design of an author-tool, based on STORM and LORA, which creates scenarios by demonstration.
- design of a parameterizable mecanism able to suggest in a given context, the best candidate for an action.

You can find more informations on those points in the "new results" section. Our partner ENIB is concerned by the pedagogic point of view of the training, so we won't talk about this part of GVT here. The main goal of this overall project is to produce a real application in order to validate all the new concepts we introduce. This application has already been shown at different meetings: Eurosatory, Le Bourget, Laval-Virtual, AFRV days and Intuition workshop. The GVT project leads to the depot of 5 french patents and 1 european patent, and a PhD has been defended. More informations on the product can be found in section 5.5.

7.2. RNTL Open-ViBE : An Open-Source Software for Brain-Computer Interfaces and Virtual Reality

Keywords: *Brain-Computer Interfaces*, *ElectroEncephaloGraphy (EEG)*, *Virtual Reality*.

Participants: Anatole Lécuyer, Yann Renard, Fabien Lotte, Vincent Delannoy, Nicolas Brodu.

The aim of the Open-ViBE project is to develop an open-source software environment enclosing novel and efficient techniques for Brain-Computer Interfaces and Virtual Reality.

Brain-Computer Interfaces are novel interfaces that measure the cerebral activity of the user (using for instance EEG acquisition machines) and translate it into a command for a computer or another system (robot, machine, car, etc).

The two main innovations that the Open-ViBE project focuses are : (1) new techniques for processing and identification of cerebral data based on neurophysiological experimentations that will identify the best physiological indicators (using real-time EEG-based source localisation techniques), and (2) new techniques to send back information to the user of the BCI about his/her mental activity (using Virtual Reality technologies: i.e. audio, visual and haptic feedback), which could then be used to improve the learning and the control of the mental activity.

Open-ViBE involves 6 partners: INRIA/BUNRAKU (Virtual Reality), INSERM (Neurophysiology), FRANCE TELECOM (Multimedia applications), INPG-GIPSALab (signal processing), CEA (signal processing) and AFM (evaluation with disabled people).

Applications of Open-ViBE are numerous. Our consortium focuses on multimedia applications (video games, theme parks) and medical applications, devoted notably to disabled people (re-education, therapy, assistance, accessibility).

In the end, the Open-ViBE project must lead to an open-source software distributed over the internet (gforge INRIA).

Three demonstrators will also be built to illustrate the numerous possibilities of our technology, in the field of multimedia and assistance to disabled people.

More information can be found on the OpenViBE website : http://www.irisa.fr/bunraku/OpenViBE

7.3. PERF-RV2

Keywords: *Behaviour Modeling*, *Informed Environment*, *Scenario Language*, *Virtual Humans*, *Virtual Reality*.

Participants: Julien Bilavarn, Stéphane Donikian [contact], Fabrice Lamarche, Michaël Rouillé.

The aim of the PERF-RV2 project is to explore the topic of the human activity in the context of a future factory. PERF-RV2 is a national research platform composed by 10 Academic partners (Armines, CEA LIST, INRIA, LAAS, LEI, LIMSI-CNRS, LIRIS, LPBEM, LPPA, LRP) and 11 Industrial partners (AFPA, Clarté, EADS CCR, Dassault Aviation, GIAT Industries, HAPTION, INRS, NewPhénix, PSA Peugeot Citroën, Renault, Vecsys). The project is decomposed into four technical Work Packages: physical and motor level, behavioural level, interaction between a human operator and a 3D environment, scenario authoring of the human experience. We are participating to the four work packages and leading two of them concerning human behaviour and scenario authoring.

- Work package 1, physical and motor level

  Goals : modeling human-like real-time behaviours for posture, prehension, poise, movement realism and cooperative work.

  Our part : in charge of the scientific state of the arts and specification of the link between the physical level (work package 1), the behavioural level (work package 2) and the scenario (work package 4).
- Work package 2, behavioral level

  Goals : development of a cognitive activity model for one or many human operators in an industrial process. Modeling a suitable environment for the actions and the perceptions of a virtual human.

  Our part :
  - field studies for the AFPA and Nexter scenarios
  - formalisation of the AFPA and Nexter scenarios using K-Made and Euterpe Task Analysis tools
  - specification of the human activity model
  - detailed specification of the informed environment model
- Work package 3, interaction between a human operator and a 3D environment

  Goals : directing a virtual human by using natural language speech, gesture, or haptic technology.

  Our part : development of the high-level control of a vitual human.
- Work package 4, scenario

  Goals : development of a scenario authoring language permitting to describe multiple users interacting in a virtual environment.

  Our part : leading, detailed specification of the scenario language functionalities.
  - leading
  - field studies for the AFPA and Nexter scenarios
  - detailed specification of the scenario language functionalities
- Demonstration

  Realization of a demonstration for the Nexter scenario, using gesture recognition to guide heavy vehicles in a virtual environment simulated by OpenMASK.

7.4. Part@ge

Participants: Bruno Arnaldi [contact], Laurent Aguerreche, Benoît Chanclou, Alain Chauffaut, Georges Dumont, Thierry Duval, 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.

Figure 34. PerfRV2: Nexter Demonstration

The aim of the Part@ge project is to provide new tools and solutions for collaboration within 3D virtual environments.

The project 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 the leader of the project, we are participating to the four work packages and we are leading one of them concerning advanced collaboration.

The Part@ge project is based on OpenMASK (our VR-platform), Spin3D (the FT R&D VR-platform) and Virtools. Our developments should be used for any of these three platforms.

We focus our activity into the following points:

- 3D formats for collaboration,
- haptic perception,
- paradigms for collaboration,
- distant haptic interaction,
- multimodal collaboration,
- interoperability for collaboration between different software platforms.

We have animated the 3 Part@ge workshops of the year, and participated to numerous smaller work sessions with our partners about our points of interest.

We also collaborate with another ANR Project: the SCOS Project, about 3D visualisation of scientific data (results of scientific calculations upon physical data) and 3D collaboration between several users working with these results.

7.5. "system@tic" : Digital Plant

Participants: Stéphane Donikian, Franck Multon [contact], Yann Pinczon du Sel.

"Digital Plant" project of the national industrial cluster "system@tic" driven by EADS CCR with many industrial (Dassault Systems, Dassault Aviation, Renault, ILOG) and academic (CEA, ENS Cachan, Supelec, ...) partners. The goal of this project was to propose a national industrial software platform for simulating and optimizing a plant. We were working in the work package entitled "contribution to the virtual human" driven by Dassault Systems. The goal was to propose techniques to animate and control virtual humans that have to work in the virtual plant. The solution found was an integration of MKM (cf paragraph 5.3) within Virtools (a software designed to add script based comportments to virtual objets). This allow virtual humans animated by MKM to use the tools given by Virtools, like path finding in the plant. It also allow the humans to adapt their motion to the tasks that have been designed for them (for instance, drilling a hole in a different position than the one in the original motion). As a result, the integration of MKM in Virtools was used to realize two industrials scenarios : one in an Airbus assembly line and another in an Altis factory of semiconductors. In both scenarios, the animation of tasks that the virtual workers had to do were done using MKM, as illustrated in figure 35.

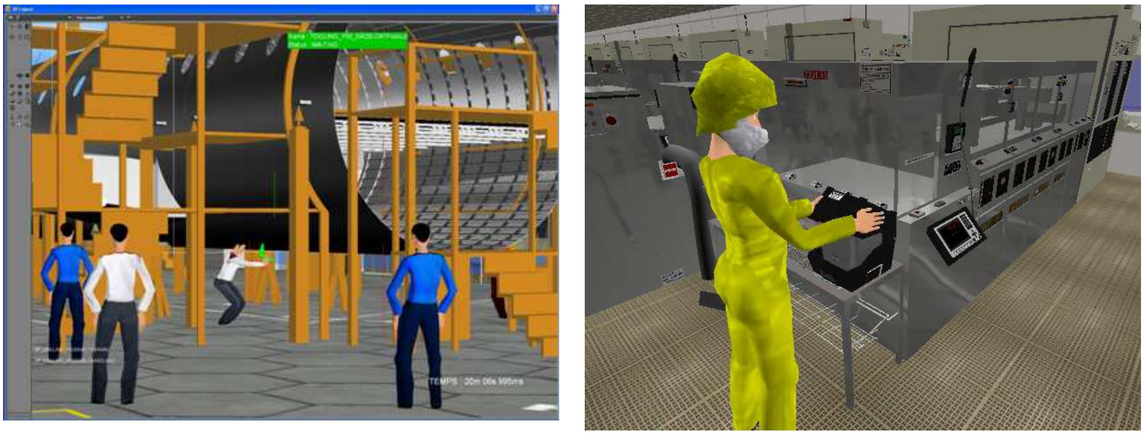


Figure 35. Example of virtual humans animated by MKM within Virtools software, in an Airbus assembly line and in an Altis semiconductor factory

The project is finished in 2007 but a new one has begun this summer: "Digital Plant 2". This project is mainly focusing on adding behaviors and high-level control on virtual humans. For example, the virtual workers should be able to collaborate in a complex world in order to carry large objects or to navigate in the Digital Plant.

7.6. CONCEPTMOVE

Keywords: *Interactive Art Installation*, *Scenario Language*, *Virtual Reality*.

Participants: Yves Bekkers, Gildas Clénet, Stéphane Donikian [contact].

Interactive poly-artistic works is a type of expression becoming increasingly common nowadays. Consequently, users, specta(c)tors, expect more and more to play an active part in these works. Poly-artistic works often come up against two kinds of problems: heterogeneity of technologies on the one hand, and lack of abstraction to write the global structure of a piece on the other hand. However, despite this important profusion in terms of technical tools, several issues remain unsolved when realizing such artistic works. First, in the context of collaborative arts, existing frameworks do not provide means for conceptualizing art pieces for contributors coming from different artistic areas (composition, choreography, video, 3D graphics).

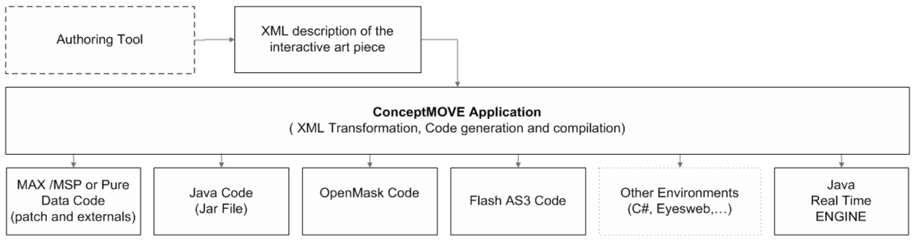


Figure 36. Overall transformation process.

Second, establishing communications between software or hardware components is often complicated. Finally, the communication process and its language have to be redefined from scratch for each new realization. Concerning communication, a certain number of artistic works presented these last years used the OSC (Open Sound Control) protocol. This protocol developed by Matt Wright at the University of Berkeley in the United States allows making communicate together computers, synthesizers and other multi-media peripherals. OSC is functioning as a client/server mechanism with the transmission of units of data. This protocol is integrated today within a certain number of software such as EyesWeb, Max/MSP, PureData and OpenMASK. Unfortunately, the source data being able to be integrated (packed up) in an OSC message are very rudimentary: integer, real, string and temporal stamp.

ConceptMove is a partnership between Danse 34 Production, IRCAM and our team. The aim of this project is 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. Our objective is to facilitate the realization of interactive poly-artistic art pieces in several ways. First, the communication process should be as transparent as possible to the users. Second, the artists should be in a position to use their favorite environments or software components in order to fulfill their ideas. And last, we wish to provide a symbolic shared area to specify the relationships between the different artistic worlds so that artists coming from various domains have a common language to start working on. Thus, the key idea is to describe poly-artistic interactive art pieces in a most generic way, regardless of the various software, hardware and environments that will be used to implement concretely the functionalities.

The first work package was devoted to the user requirement gathering. For that purpose, we have written a state of the art of the existing languages used in the different artistic communities, we have organized in June in Paris a two days international symposium entitled *Writing Time and Interaction*, and we have asked people to fill in a questionnaire. After analyzing the brake that slow down artistic creation in poly-artistic works, we developed, within the ConceptMove project, a meta-language with the aim of solving some of these problems. This language, a XML dialect, describes communications and time constraints of a piece, in a unified paradigm. Even if this approach may not be suitable for some situations needing fine grained interactivity (score following to name one), it proposes a convenient formalism for lots of other situations like virtual and augmented realities, as well as interactive narration. Once the overall description of the piece is achieved with the meta-language, including interactive specifications and temporal constraints, it is time to choose what environment or programming language the different people involved wish to use (cf figure 36). As this XML description will be the source of different plug-ins (currently implemented are Max/MSP, Pure Data, Listenspace, OpenMASK, Java), there is technically no limitation in the range of software one can use. This architecture can also communicate with existing material, assuming they already had an OSC communication: the generated code will automatically match the particular protocol.

The part, handling the communication, relies on an existing standard, WSDL, which allows describing the way an application communicates with the rest of the world. But there are also complementary temporal constraints that enable hierarchical and complex relations between temporal objects. This makes it possible for the code

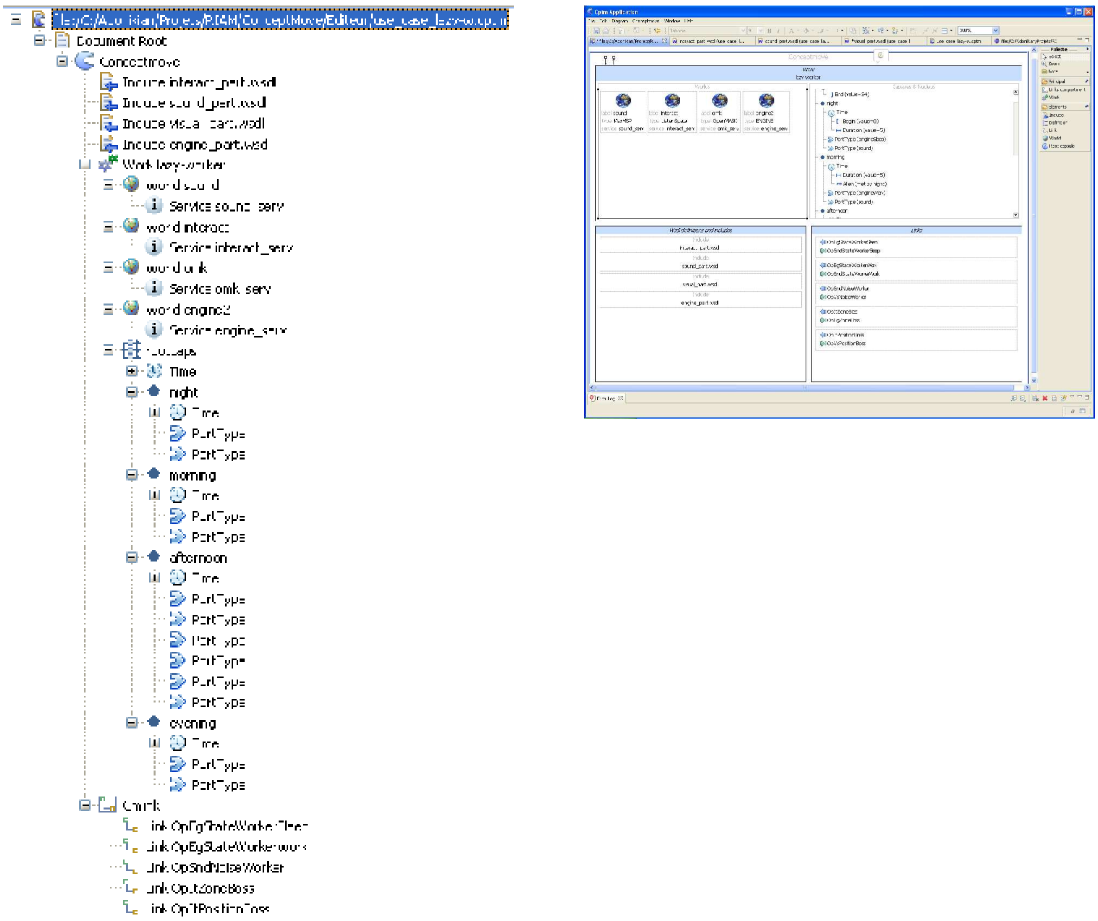


Figure 37. Views of the Authoring tool on the Lazy Worker example.

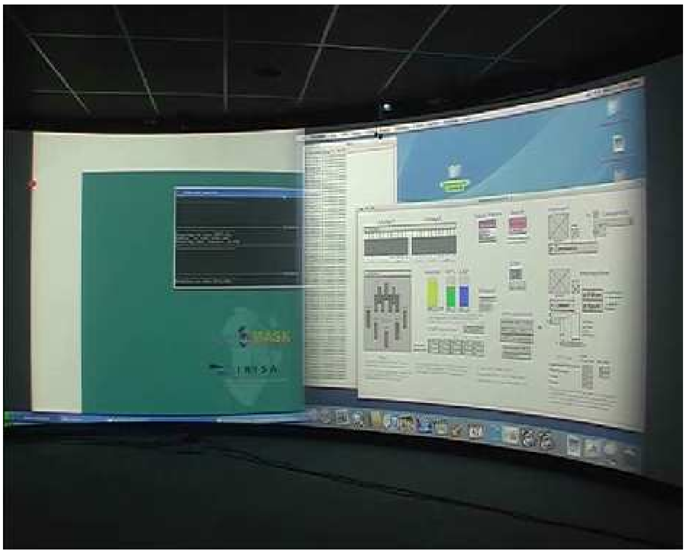


Figure 38. User Interactivity test in Seule avec loup, an interactive choreography by N+N Corsino.

generator to create the "engine" of the art piece, e.g. a simple application that will schedule events in real time. This application will send start and stop events on time, but will also receive requests to start or stop temporal objects from the outside, enabling this way dynamic modification of temporal structures, through interaction for instance. Such constraint requests will of course be ignored if they turn to be inconsistent with written script of the piece. The written script is and stays the main reference and score for generated material and structural events. After addressing the main issues through code generation, we proposed an intuitive graphical authoring tool that places the XML meta-language at a comprehensive level. This tool is implemented as an eclipse plug-in and allows specifying the art piece from the most abstract level down to the implementation details. Once the piece is fully described, the authoring tool generates and equivalent XML description that will then be used for the transformation and code generation described previously.

The Meta Language has already been used for short examples such as the Lazy Worker example (cf figure 37) but also in a new version of *Seule avec loup*, an interactive choreography by N+N Corsino. This new version includes more interactivity between the user and the music composed in real-time (cf figure 38).

7.7. SIMULEM

Keywords: *Crowd Simulation*, *Train Station Simulator*.

Participants: Vincent Delannoy, Stéphane Donikian [contact], Delphine Lefebvre, Sébastien Paris.

The exploitation of large transportation facilities, such as train stations or airports, is requesting a specific expertise on the crowd phenomenon. Existing commercial simulation tools only address the most visible behavior of human beings, the navigation, and thus the environment is only considered as a set of obstacles to avoid. In this case, the objectives of the simulated pedestrians are only a set of predefined destinations in the environment. However, real humans achieve higher level goals usually related to the interactions they must accomplish within their environment. In a train station it consists for example in buying a ticket, consulting the departure board, and so on. These interactions have a strong impact on the navigation tasks because they define a set of emergent destinations for a simulated pedestrian, and also provoke waiting queue formations. Thus, a goal oriented behavior based on interactions with equipments should be placed at the heart of a simulation tool in order to obtain realistic results.

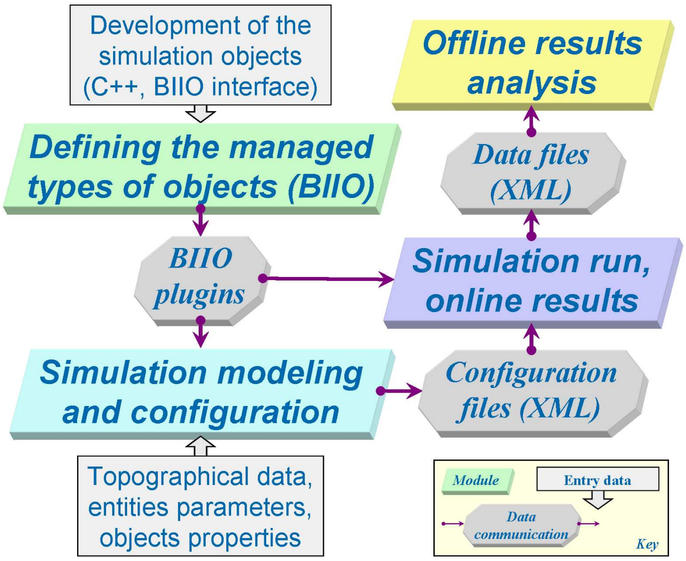


Figure 39. The Simulem application architecture.

The Simulem Project is conducted in partnership with AREP, a subsidiary company of the French railway company SNCF. AREP is an engineering and design department interested mainly in the design and installation of exchange areas such as the train stations. The project consists in designing the first simulation tool allowing to simulate individual and collective activities of autonomous agents in a public environment such as a railway station (cf figure 39).

We present a novel pedestrian simulation architecture able to perform such a goal oriented behavior. Our approach combines two main components to achieve this objective. First, a realistic environment description represents exactly the geometry and topology of a public building. This environment is informed with interactive objects which situate the interaction opportunities, allowing to include them in the decision process associated with the navigation task of a virtual human. Second, our virtual human is able to take advantage of this informed environment to perform some interactions with regard to its goal oriented behavior. Thus, the decision process of our virtual human takes into account its final goal, including all the necessary interactions to reach this goal and their impact on the navigation.

Indeed, the decision process of our autonomous agent is multi-layered, with four levels of behaviors:

- Social level which manages the self organization of people in order to perform an interaction (waiting queue and using area).
- Rational level which is in charge of the logical decision related to the interaction (the goal oriented behaviour).
- Cognitive level which is in charge of the situated decision of the virtual human, with a topological knowledge and the path planning.
- Reactive level which manages the most specialized behaviors, with the visual perception and a realistic approach of the reactive navigation.

Finally, all of these models are integrated in a simulation tool, called SIMULEM, which allows to manage the entire simulation process:

Figure 40. Example of the 3D graphical output of SIMULEM. Here we can see some waiting queue formations in front of ticket selling machines, while other people walk to reach other goals.

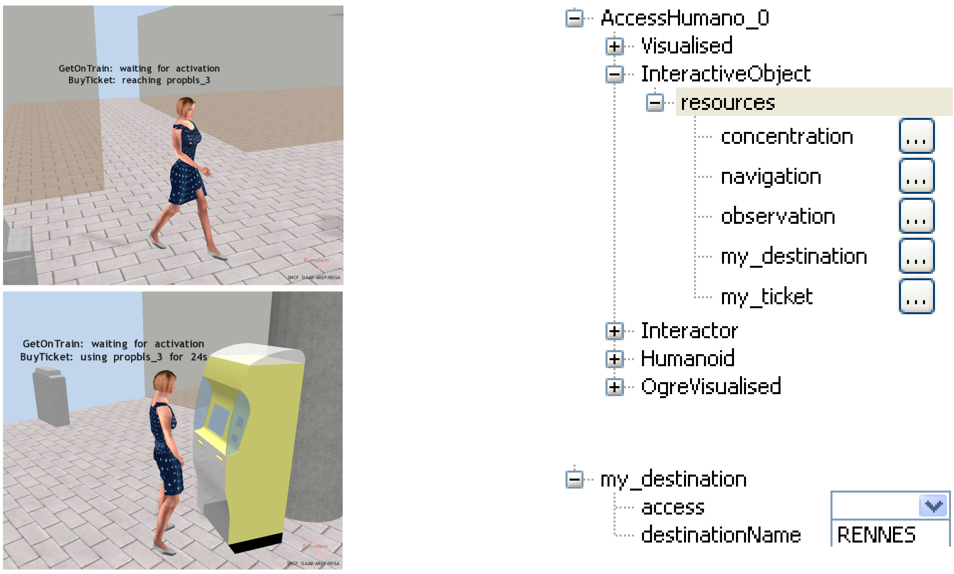


Figure 41. Example of a performed interaction by an outgoing passenger. Its current goals are directly listed on the pictures. The right table shows the internal state of this passenger with a user interface.

Describing the input data, such as the environment map, the positions of the equipments, or more functional information such as the train departure timetable.

Simulating (40) the users of the environment, with different goals (41), knowledges, or initial states.

Extracting some results (42), corresponding to the quality of services offered by the environment to the users.

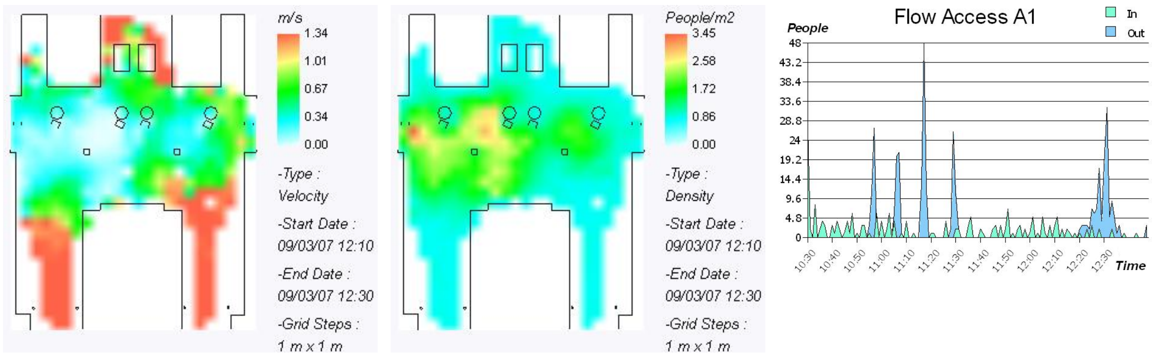


Figure 42. Examples of the results output of SIMULEM. 2D maps: the average speeds (left) and local densities of people (middle) for a given time interval in the environment. Right graph: incoming and outgoing flows of people for one access of the environment through time.

8. Other Grants and Activities

8.1. NoE: Intuition

Participants: Bruno Arnaldi [contact], Anatole Lécuyer, Yann Jehanneuf.

We are member of the core group of INTUITION : VIRTUAL REALITY AND VIRTUAL ENVIRONMENTS APPLICATIONS FOR FUTURE WORKSPACES which is a Network of Excellence involving more than 68 european partners form 15 different countries. This project belongs to the joint call IST-NMP of the FP6 program.

INTUITION's major objective is to bring together leading experts and key actors across all major areas of VR understanding, development, testing and application in Europe, including industrial representatives and key research institutes and universities in order to overcome fragmentation and promote VE establishment within product and process design. To perform this, a number of activities will be carried out in order to establish a common view of VR technology current status, open issues and future trends.

Thus the INTUITION Network aims are:

- Systematically acquire and cluster knowledge on VR concepts, methodologies and guidelines, to provide a thorough picture of the state of the art and provide a reference point for future project development;
- Perform an initial review of existing and emerging VR systems and VE applications, and establish a framework of relevant problems and limitations to be overcome;
- Identify user requirements and wishes and also new promising application fields for VR technologies.

8.1.1. Management of “Haptic Interaction” Working Group

Anatole Lécuyer is the leader of the "Haptic Interaction" Working Group (WG 2.10). The main objective of the Haptic Interaction Working Group is to federate strongly the major European actors in Haptics and to promote their joint activity. The objectives of the first 18 months of the WG were to provide feedback concerning the Haptic Interaction field and to exploit knowledge emanating from Cluster "Integrating and structuring activities" regarding the Haptic Interaction domain.

Key achievements:

- Animation of the WG Haptic Forum (Sept 06->)
- Preparation, organisation, participation and minutes of WG Meeting in Basel 4th December (Sept-Dec 06)
- Preparation, organisation, participation and minutes of Cross-WG Meeting with WG Engineering and Design in Basel 4th December (Sept-Dec 06)
- Preparation, discussion and organisation of a tutorial on Integration of haptic in VE at IEEE VR 2007 (Oct 06->)
- Preparation of INTUITION EC Review in Stuttgart (Nov 06)
- Preparation and discussion about European course on haptics (Nov 06->)
- Preparation and discussion about Standards of haptics (Nov 06->)
- Poster for the 3rd INTUITION Workshop of Stuttgart (Nov 06)
- Papers for the 3rd INTUITION Workshop of Stuttgart (Nov 06)
- Special session on Haptic and locomotion interfaces for 3rd INTUITION Workshop : S. Coquillart (INRIA); S. Cardin (EPFL); J. Souman (MPI)
- Demos for the 3rd INTUITION Workshop of Stuttgart (Nov 06)
- Organisation and participation in WorldHaptics Conference 2007 (Nov 06->)
- Participation in the IEEE Technical Committee on Haptics (Dec 06->)
- Preparation of WG meeting in Laval on April 18th (Jan 07->)
- Preparation, organization, participation and minutes of Cross-WG Meeting with WG Education and Train Arpil 18th (Jan 07)
- Preparation and participation in WG Leaders meetings in Stuttgart, Basel and Athens on (Dec 06->Feb 07)
- Preparation of a Special session on Haptics for Medical Applications at ECC 2007 (ICCS-CNRS)
- Preparation of Special session on Haptic in Cyberworld (Cyberworlds 2006 EPFL)
- Preparation, organization, participation and minutes of 2 WG Meetings : Basel 4th December, Laval 18th April
- Preparation, organization, participation of 3 Cross-WG Meetings : with WG Engineering and Design in Basel 4th December, with WG Aerospace in Torino January18th-19th, with WG Education and Training in Laval 18th April
- Preparation and participation in 3 WG Leaders Meetings in Stuttgart (Nov.), Basel (Dec.) and Athens (Feb.)
- Preparation and discussion about European courses on haptics
- Preparation and discussion about Standards of haptics
- Discussion and contribution to the INTUITION knowledgebase
- Participation and submission of new research proposals
- Organization of a tutorial at IEEE VR 2007 in March 2007, on Integration of haptics in VE
- Strong participation in the WorldHaptics Conference, in Tsukuba, Japan, March 2007
- Participation in special session at IPT/EGVE on Human Perception and Virtual Environments in July 15-18th
- Involvement in the newly founded Eurohaptics Society (CNRS, ETH, MPI, etc)
- Strong involvement and participation in the IEEE Technical Committee on Haptics: meeting, sharing of documents (report on WHC 2007, Research Roadmap), common actions, etc

The Term of Reference of the INTUITION Working Group on Haptic Interaction provides the description of the WG, its relevant area, its research needs and the research topics to be addressed. An international aspect is given to the research area addressed by briefly describing the international related activities that might be relative to the WG and by positioning Europe in a worldwide scale. Complementary, the State-of-the-Art of technology in the field of haptic interaction is described.

8.1.2. Management of "Business Office" within the Network sustainability Work Package

Bruno Arnaldi and Yann Jehanneuf are the leaders of the "Business Office" (BO) Subtask (1.F.2) within the Work Package (WP1.F). The major activity of this task is the establishment and operation of the Network Business Office. The Business Office is the part dedicated to the marketing and the promotion of the INTUITION Association. In general the BO will act as the face of the Association and it will be the responsible entity for the dissemination of the association. This body will receive input from WP3.4 concerning exploitation aspects of INTUITION related efforts and from all Network bodies. It shall work as a liaison body among third parties and the Network competencies. The INTUITION association has been defined and the strategy of the BO together with the identification of the most efficient legal structure for this, have been initially reported in D1.F_2: Network Business Office operational framework and business plan. The BO shall try to set up the appropriate start-up of the Association. Key achievements:

- Work in close collaboration with L-Up upon the INTUITION Business Plan (Sep 06 to Feb 07)
- Meetings with L-Up (Sep 06, Feb 07)
- Organization of several phone conferences with the Business Plan evaluation committee (Sept 06 to Feb 07)
- Preparation and participation at the NMC meeting and WG leader meeting in Basel (Oct'06)
- Preparation and participation of WG Meeting in Stuttgart General Assembly (Nov'06)
- Preparation and participation to the INTUITION Workshop in Stuttgart (Nov'06)
- Preparation and participation of INTUITION EC Review (Nov 06)
- NMC phone meeting (Dec'06)
- Discussions, preparation and submission of an Internal Project between with INRIA and AAS (Dec 07)
- Preparation and participation at the NMC meeting and WG leader meeting in Athens (Feb'07)
- Submission of the deliverable D1.F_2 (March 07)
- Preparation and participation to WG Meeting in Laval Virtual (April'07)
- Participation to WG meeting in Laval (April'07)
- Preparation and participation at the Review in Brussels (May'07)
- Participation to Annecy conference (June'07)
- Work on the deliverable D1.F_3 (June 07)
- Work on Association marketing presentation (July 07)
- Work on the update of the JPA (Aug'07)
- Preparation of a poster and leaflet for the Association dedicated to the Workshop in Athens (Sept'07)
- Preparation and participation of WG Meetings, the General Assembly and the Workshop in Athens (Oct'07)
- Presentation of the European VR Association at the General Assembly (Oct 07)

Figure 43. INRIA-Business Office booth

The main Deliverable D1.F_2 report will include the description of the Operational framework of the Association. One of the major tasks of INTUITION will be the sustainability of the network beyond the period of EU support. This task has been going on since the beginning of the network and will investigate all possible ways of doing this from the legal, financial and organizational point of view. Thus, the document focuses on the future organization, the position of the Business Office (BO) and the introduction of the Business Plan. Within the preparation of the related Business Plan (BP) for this foreseen entity, this report shall not duplicate the business plan, but rather draft some large trends on the targeted project (creation of an entity being a European non profit making association), based on rather qualitative criteria of assessment. Indeed, the details of the invitation to tender with his procedure are described in order to explain how we have chosen L-up Company to support us in the Business Plan elaboration. This final version is enriched with a detailed analysis for products and services, financial analysis and all the elements which enable the making a concrete business plan for the future organization.

8.1.3. Intuition's consortium members

ICCS, Alenia, CEA, CERTH, COAT-Basel, CRF, INRIA Rhône-Alpes, FhG-IAO, UNOT, USAL, VTEC, VTT, ART, ALA, ARMINES, BARCO, CSR SRL, CLARTE, CNRS (5 laboratories), CS, Dassault Aviation, EADS, ENIB, EPFL, EDAG, EDF, ESA, ICS-FORTH, FHW, FTRD, FhG-IPK, FhG-FIT, LABEIN, HUT, ICIDO, INRS, IDG, MPITuebingen, UTBv, NNC, ONDIM, OVIDIUS, PERCRO, PUE, RTT, SNCF, SpaceApps, ETH, TUM, TECNATOM, TILS, TVP - S.A., TGS Europe, TNO, UPM, UCY, UNIGE, UMA, UniPatras, UoS, Twente, IR-UVEG, UoW, Plzen.

9. Dissemination

9.1. Scientific Community Animation

- Member of the Francophone Association about Human-Machine Interaction (AFIHM): T. Duval.
- T. Duval is reviewer of the IEEE VR 2007 Conference, of the Graphics Interface 2007 Conference and of the IHM 2007 Conference.

- N. Mollet is reviewer of IEEE VR 2007 Conference.
- N. Mollet is an INRIA member of the Working Group Virtual Reality for Training, within the INTUITION European Network of Excellence.
- Member of ACM SIGGRAPH and Eurographics: F. Multon
- F. Multon was member of the International Program Committee of ACM SIGGRAPH/Eurographics Symposium on Computer Animation 2006
- Leader of the Working Group on Haptic Interaction, within the INTUITION European Network of Excellence: A. Lécuyer.
- Scientific expert for the French National Association for Research (ANR) and the Dutch Research Foundation (NWO): A. Lécuyer.
- S. Donikian has been member this year of the Program Committee of the following international conferences: ACM/Eurographics SCA'07, CASA'07, GRAPP'07, EDUTAINMENT07.
- Chief Editor of the *Revue Electronique Francophone d'Informatique Graphique* (french computer graphics electronic journal): S. Donikian.
- S. Donikian is Conference Chair of the fourth International Conference on Virtual Storytelling, December 5-7, Saint-Malo, France.
- Reviewers for international journal such as IEEE Transaction on Vizualization and Computer Graphics, ACM Transaction on Graphics, Computer Graphics Forum, Computer Animation and Virtual Worlds, ETRI Journal and Graphical Models: S. Donikian.
- Reviewer for Eurographics'07, SIGGRAPH'07, AISB 2006 Symposium on Narrative AI and Games, LUDOVIA'06: S. Donikian.
- Active member of AFIG (French Association for Computer Graphics - member of the board of directors of the association: S. Donikian.
- Co-animator of the french working group on Animation and Simulation: S. Donikian.
- Expertise for national and european agencies of academic and industrial projects in the fields of virtual reality, computer graphics and computer games: S. Donikian
- Member of the programme committee of several conferences : Grapp'2007, Grafite2007, EG symposium on Rendering'2007, Pacific Graphics'2007: K. Bouatouch.
- Member of the Editorial Board of the Visual Computer Journal: K. Bouatouch.
- Responsible for a collaboration with the computer graphics group of the University of Central Florida: K. Bouatouch.
- External examiner of PhD and member of promotion committees in US, France, Cyprus: K. Bouatouch.
- Member / Reviewer of AFIG (French Association for Computer Graphics): F. Lamarche.
- Reviewer of REFIG (French review of computer graphics): F. Lamarche.
- Member of the program commitee and reviewer for the Web3D Symposium 2007 (April 2007): C. Bouville.
- Reviewer for Graphite 2007 (December 2007): C. Bouville.
- Reviewer for Annales des Télécommunications: C. Bouville.
- Member of the Organising Committee of the International Workshop On Constraint-based Layout of Diagrams and Documents, 23rd September 2007: M. Christie.
- Director of Computer Science Research Laboratory of INSA de Rennes: B. Arnaldi.
- Vice-president of AFRV (French Association for VR) until october 2007 and President from october 2007: B. Arnaldi.

- Member of the Network Management Committee of NoE INTUITION: B. Arnaldi.
- Chairman of Part@ge ANR Project dedicated to Collaborative Interaction: B. Arnaldi.
- Member of "comité d'évaluation" TechLog ANR until July 2007: B. Arnaldi.
- Member of Executive Board RNTL until July 2007: B. Arnaldi.
- B. Arnaldi has been member this year of the Program Committee of the following international conferences: ACM/Eurographics SCA'07, VRST'07 and MIRAGE'07.

9.2. Courses in Universities

- Mechanical Agregation course: mechanical science, plasticity, finite element method. ENS Cachan (G. Dumont).
- Teaching in numerical tools for mechanical simulation. ENS Cachan (G. Dumont).
- MASTER MN-RV (Master of Numerical Models and Virtual Reality, University of Maine, Laval, France) : Physical models for virtual reality (G. Dumont).
- Responsible for the Software Engineering Speciality (GL) of the MASTER OF COMPUTER SCIENCE Ifsic (T. Duval).
- DIIC LSI, MASTER OF COMPUTER SCIENCE GL AND MITIC Ifsic : Man-Machine Interfaces and Design of Interactive Applications (T. Duval).
- MASTER OF COMPUTER SCIENCE Ifsic : Introduction to Computer Graphics (T. Duval).
- MASTER OF COMPUTER SCIENCE Ifsic : Collaborative Virtual Environments with OpenMASK (T. Duval).
- MASTER OF COMPUTER SCIENCE University of Nantes : Introduction to Collaborative Virtual Environments (T. Duval).
- Director of the engineering degree in computer science and communication of the IFSIC institute (K. Bouatouch.
- Responsible for a course MASTER OF COMPUTER SCIENCE Ifsic: Coding Transmission and Rendering of Video, Audio and 3D Data (CTR) (K. Bouatouch).
- MASTER MITIC (IFSIC), Modelling, Animation and Rendering (R. Cozot and F. Lamarche).
- DIIC (IFSIC), Algorithmic and Programming (F. Lamarche).
- DIIC INC (IFSIC), Animation (F. Lamarche).
- DIIC INC (IFSIC), Image Synthesis (K. Bouatouch, R. Cozot and F. Lamarche).
- LICENCE 2 (IFSIC), Reactive system conception (F. Lamarche).
- Computer Science MASTER OF COMPUTER SCIENCE, MR2I Ifsic, INSA de Rennes, ...: Virtual and Augmented Reality (VAR) (B. Arnaldi and E. Marchand).
- Responsible for the Track Images and Interactions of the MASTER OF COMPUTER SCIENCE, MR2I Ifsic, INSA de Rennes, ... (B. Arnaldi).
- MASTER OF COMPUTER SCIENCE Ifsic : Image and Motion (F. Multon).
- INSA DE LYON, Techniques et application du Web3D (C. Bouville)
- Responsible for the Digital Imaging and Communication Speciality (INC) of the engineering degree in computer science and communication of the IFSIC institute (R. Cozot).
- MASTER CCI (IFSIC), Modelling, Animation and Rendering (R. Cozot).
- MASTER MITIC (IFSIC), Video, Image and Sound (R. Cozot).
- MASTER OF COMPUTER SCIENCE Ifsic : Responsible of the organization of the colloquium (COLQ), the Master defense and the cycle of conferences (META) (S. Donikian).

10. Bibliography

Major publications by the team in recent years

[1] B. BIDEAU, R. KULPA, S. MÉNARDAIS, F. MULTON, P. DELAMARCHE, B. ARNALDI. *Real handball keeper vs. virtual handball player: a case study*, in "Presence - Teleoperators and Virtual Environments", vol. 12, 2003, p. 411-421.

[2] M. CONGEDO, A. LÉCUYER, E. GENTAZ. *The Influence of Spatial De-location on Perceptual Integration of Vision and Touch*, in "Presence - Teleoperators and Virtual Environments", vol. 15, n^{o} 3, 2006.

[3] G. DUMONT, J.-M. SOUFFEZ. *FE Meshes Preparation for interactive Analysis in Virtual Reality*, in "Research in Interactive Design (Proceedings of Virtual Concept 2006)", ISBN: 978-2-287-48363-9, 2007.

[4] R. KULPA, F. MULTON, B. ARNALDI. *Morphology-independent representation of motions for interactive human-like animation*, in "Computer Graphics Forum", vol. 24, n^{o} 3, 2005.

[5] F. LAMARCHE, S. DONIKIAN. *Crowd of Virtual Humans: a New Approach for Real Time Navigation in Complex and Structured Environments*, in "Computer Graphics Forum - Eurographics 2004", vol. 23, n^{o} 3, 2004.

[6] S. PARIS, S. DONIKIAN, N. BONVALET. *Environmental Abstraction and Path Planning Techniques for Realistic Crowd Simulation*, in "Computer Animation and Virtual Worlds", vol. 17, n^{o} 3-4, 2006, p. 325-335.

[7] N. PRONOST, G. DUMONT, G. BERILLON, G. NICOLAS. *Morphological and stance interpolations in database for simulating bipedalism of virtual humans*, in "The Visual Computer", vol. 22, n^{o} 1, January 2006, p. 4-13.

[8] J. SRENG, A. LÉCUYER, C. ANDRIOT, C. MÉGARD. *Using Visual Cues of Contact to Improve Interactive Manipulation of Virtual Objects in Industrial Assembly/Maintenance Simulations*, in "IEEE Transactions on Visualization and Computer Graphics", vol. 12, n^{o} 5, 2006, p. 1013–1020.

Year Publications

Books and Monographs

[9] M. CAVAZZA, S. DONIKIAN (editors). *Virtual Storytelling. Using Virtual Reality Technologies for Storytelling, 4th International Conference, ICVS 2007*, LNCS, vol. 4871, Springer, Saint-Malo, France, December 2007.

Doctoral dissertations and Habilitation theses

[10] S. PARIS. *Caractérisation des niveaux de services et modélisation des circulations de personnes dans les lieux d'échanges*, Ph. D. Thesis, MATISSE, November 2007.

Articles in refereed journals and book chapters

[11] M. BADAWI, S. DONIKIAN. *The generic description and management of interaction between autonomous agents and objects in an informed virtual environment*, in "Comput. Animat. Virtual Worlds", vol. 18, n^{o} 4-5, 2007, p. 559–569.

[12] H. BENTOUMI, P. GAUTRON, K. BOUATOUCH. *GPU-Based Volume Rendering for Medical Imagery*, in "International Journal of Computer systems Science and Engineering", vol. 1, n^{o} 1, 2007.

[13] M. CHRISTIE, P. OLIVIER, J.-M. NORMAND. *Virtual Camera Control*, in "Computer Graphics Forum", to appear, 2007.

[14] L. DOMINJON, J. PERRET, A. LÉCUYER. *Novel Devices and Novel Interaction Techniques for Human-Scale Haptics*, in "The Visual Computer", vol. 23, n^{o} 3, 2007.

[15] G. FRANÇOIS, S. PATTANAIK, K. BOUATOUCH, G. BRETON. *Subsurface Texture Mapping*, in "IEEE Computer Graphics & Applications", To appear, vol. 28, n^{o} 1, 2008.

[16] P. GAUTRON, K. BOUATOUCH, S. PATTANAIK. *Temporal Radiance Caching*, in "IEEE Transactions on Visualization and Computer Graphics journal", vol. 1, n^{o} 5, September/October 2007.

[17] S. GERBAUD, B. ARNALDI, J. TISSEAU. *GVT: Virtual Training in Maintenance Procedures*, in "ERCIM News", vol. 71, October 2007, p. 44–45.

[18] S. GIBET, A. HÉLOIR, N. COURTY, J. KAMP, N. REZZOUG, P. GORCE, F. MULTON, C. PELACHAUD. *Virtual Agent for Deaf Signing Gestures*, in "ASME Journal of Dynamic Systems, Measurement, and Control", to appear, 2007.

[19] R. KULPA, F. MULTON. *Natural posture prediction using fast iterative algorithms*, in "Computer Methods in Biomechanics and Biomechanical Engineering", vol. 10, n^{o} S1, 2007, p. 51-52.

[20] F. LOTTE, M. CONGEDO, A. LÉCUYER, F. LAMARCHE, B. ARNALDI. *A Review of classification algorithms for EEG-based Brain-Computer Interfaces*, in "Journal of Neural Engineering", vol. 4, 2007, p. R1-R13.

[21] F. LOTTE, A. LÉCUYER, F. LAMARCHE, B. ARNALDI. *Studying the Use of Fuzzy Inference Systems for Motor Imagery Classification*, in "IEEE Transactions on Neural System and Rehabilitation Engineering", vol. 15, n^{o} 2, 2007, p. 322-324.

[22] A. LÉCUYER, J. BURKHARDT, C. TAN. *A Study of the Modification of the Speed and Size of the Cursor for Simulating Pseudo-Haptic Bumps and Holes*, in "ACM Transactions on Applied Perception", to appear, 2007.

[23] F. MULTON, R. KULPA, B. BIDEAU. *MKM: a global framework for animating humans in virtual reality applications*, in "Presence", to appear, 2007.

[24] G. NICOLAS, F. MULTON, G. BERILLON, F. MARCHAL. *From bone to plausible bipedal locomotion using inverse kinematics*, in "Journal of Biomechanics", vol. 40, n^{o} 5, 2007, p. 1048-1057.

[25] S. PARIS, S. DONIKIAN, N. BONVALET. *Vers une architecture pour la simulation microscopique de foule*, in "REFIG, Revue Electronique d'Informatique Graphique", vol. 1, n^{o} 1, 2007, p. 33-43.

[26] S. PARIS, J. PETTRÉ, S. DONIKIAN. *Pedestrian Reactive Navigation for Crowd Simulation: a Predictive Approach*, in "Computer Graphics Forum, Eurographics'07", vol. 26, n^{o} 3, September 2007, p. 665-674.

[27] N. PRONOST, G. DUMONT. *Dynamics-based analysis and synthesis of human locomotion*, in "The Visual Computer", vol. 23, n^{o} 7, July 2007, p. 513-522.

[28] N. PRONOST, G. DUMONT. *Influences des adaptations morphologiques et cinématiques sur la dynamique des mouvements*, in "Revue Electronique Francophone d'Informatique Graphique (REFIG)", vol. 1, n^{o} 1, 2007.

[29] J. ROYAN, P. GIOIA, R. CAVAGNA, C. BOUVILLE. *Network-based visualization of very large 3D landscape and city models*, in "IEEE CG&A", to appear, vol. 27, n^{o} 5, 2007.

Publications in Conferences and Workshops

[30] O. DELERUE, S. DONIKIAN, G. CLENET. *Creating interactive poly-artistic works: the ConceptMove project*, in "ICVS'07 - Fourth International Conference on Virtual Storytelling, Saint-Malo, France", M. CAVAZZA, S. DONIKIAN (editors), December 2007.

[31] S. DONIKIAN, O. DELERUE, G. CLENET, T. BIANCO. *Towards a Complete Open Source Software Environment for the Creation of Interactive Poly-Artistic Work*, in "ICMC'07 - Immersed Music, International Computer Music Conference '07, Copenhagen, Denmark", August 2007.

[32] S. GERBAUD, N. MOLLET, B. ARNALDI. *Virtual Environments for training: from individual learning to collaboration with humanoids*, in "Edutainment, Hong Kong, China", June 2007, p. 116–127.

[33] F. GUILLAUME, P. GAUTRON, G. BRETON, K. BOUATOUCH. *Anatomically accurate modeling and rendering of the human eye*, in "Siggraph Sketch", ACM, August 2007.

[34] S. HILLAIRE, R. COZOT, A. LÉCUYER, G. CASIEZ. *Depth-of-Field Blur Effects for First-Person Navigation in Virtual environments*, in "Proc. of ACM Virtual Reality Software and Technology (VRST), Newport Beach, California, USA", ACM, 2007.

[35] A. KADRI, A. LÉCUYER, J. BURKHARDT, S. RICHIR. *The Visual Appearance of User's Avatar Can Influence the Manipulation of Both Real Devices and Virtual Objects*, in "Proceedings of IEEE International Symposium on 3D User Interfaces", 2007.

[36] F. LOTTE, A. LÉCUYER, B. ARNALDI. *FuRIA : un nouvel algorithme d'extraction de caractéristiques pour les interfaces cerveau-ordinateur utilisant modèles inverses et modèles flous*, in "Colloque GRETSI", 2007, p. 665-668.

[37] F. LOTTE, A. LÉCUYER, B. ARNALDI. *FuRIA: A Novel Feature Extraction Algorithm for Brain-Computer Interfaces Using Inverse Models and Fuzzy Region of Interest*, in "Proc. of the 3rd IEEE-EMBS international Conference on Neural Engineering", 2007, p. 175-178.

[38] F. LOTTE, A. LÉCUYER, B. ARNALDI. *Les Interfaces Cerveau-Ordinateur : Utilisation en Robotique et Avancées Récentes*, in "Journées Nationales de la Recherche en Robotique", 2007, to appear.

[39] N. MOLLET, S. GERBAUD, B. ARNALDI. *An operational VR platform for building Virtual Training Environments*, in "Edutainment, Hong Kong, China", June 2007, p. 140–151.

[40] N. MOLLET, S. GERBAUD, B. ARNALDI. *STORM: a Generic Interaction and Behavioral Model for 3D Objects and Humanoids in a Virtual Environment*, in "IPT-EGVE the 13th Eurographics Symposium on Virtual Environments", July 2007, p. 95–100.

[41] F. MULTON, L. HOYET, T. KOMURA, R. KULPA. *Dynamic motion adaptation for 3D acrobatic humanoids*, in "Proceedings of IEEE Humanoids'07, Pittsburgh, PA", November 2007.

[42] F. MULTON, L. HOYET, T. KOMURA, R. KULPA. *Interactive control of physically-valid aerial motion: application to VR training system for gymnasts*, in "Proceedings of ACM Virtual Reality Software and Technology VRST'2007", to appear, 2007.

[43] J. PETTRÉ, H. GRILLON, D. THALMANN. *Crowds of Moving Objects: Navigation Planning and Simulation*, in "IEEE International Conference on Robotics and Automation", 10-14 April 2007, p. 3062–3067.

[44] G. SOURIMANT, L. MORIN, K. BOUATOUCH. *Gps, Gis and Video fusion for urban modeling*, in "Computer Graphics International, Petropolis, Brazil", May-June 2007.

[45] G. SOURIMANT, L. MORIN, K. BOUATOUCH. *GPS, GIS AND VIDEO REGISTRATION FOR BUILDING RECONSTRUCTION*, in "ICIP, San Antonio, US", September 2007.

[46] J. SRENG, F. BERGEZ, J. LE GARREC, A. LÉCUYER, C. ANDRIOT. *Using an Event-Based Approach to Improve the Multimodal Rendering of 6DOF Virtual Contact*, in "Proceedings of ACM International Symposium on Virtual Reality Software and Technology", 2007.

Internal Reports

[47] J. BILAVARN, S. DONIKIAN. *Besoins Utilisateurs*, Technical report, INRIA, january 2007.

[48] J. BILAVARN, S. DONIKIAN. *Specifications du langage de scénario*, Technical report, INRIA, may 2007.

[49] J. BURKHARDT, S. COUIX, S. DONIKIAN, M. ROUILLÉ. *Résultats analyse ergonomique activité finalisée*, Technical report, INRIA and LEI, january 2007.

[50] T. DUVAL, L. AGUERRECHE, B. CHANCLOU, A. CHAUFFAUT, L. DOMINJON. *Paradigme d'Action Collaborative*, Technical report, INSA Rennes and CLARTE, july 2007.

[51] F. GUILLAUME, P. GAUTRON, G. BRETON, K. BOUATOUCH. *Anatomically accurate modeling and rendering of the human eye*, Technical report, IRISA, 2007.

[52] F. LAMARCHE, M. ROUILLÉ. *Spécification détaillée du modèle méréotopologique 2D1/2 de l'environnement informé*, Technical report, INRIA, may 2007.

[53] B. MERCIER, K. BOULANGER, C. BOUVILLE, K. BOUATOUCH. *Multiview Autostereoscopic Displays*, Technical report, IRISA, 2007.