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

THEME COG

Activity Report

2006

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2. Overall Objectives

2.1. Overall Objectives

The main context of our research activities concerns the **simulation of complex systems**. Indeed, our research topics deal with lighting simulation, mechanical simulation, control of dynamic systems, behavioral simulation, real time simulation and modeling of virtual environments.

Our studies are focusing on the following topics:

- **Computer Graphics**: our main works concern the design and integration of *models*, the design of new *algorithms* and of the *complexity* of the proposed solutions.
- **Simulation**: our main goal is to be able to compare the results produced by our simulation algorithms with real data in order to experimentally *validate* our approaches.
- **Systemic approach**: in order to validate the two previous points, we have to be able to treat *real industrial test cases* through the use of realistic implementation of our solutions.

More precisely, our studies deal with three complementary research themes:

- **lighting simulation**: realistic image synthesis algorithms give high quality results by the use of physical based illumination models in order to evaluate the light / material complex interactions.
- **physical system simulation**: first, our approach concerns the computation schemes needed to produce the state equations of the system (symbolic and/or numeric computation). Second, we are concerned by the control of these physical systems (virtual characters,...). In this field, we focus our attention on computer animation and simulation.
- **behavioral modeling and simulation**: in order to simulate the behavior of living beings in specific tasks, we design tools dedicated to the specification and simulation of dynamics entities (autonomous or semi-autonomous). Our behavioral models integrate continuous and discrete aspects, in one hand to be able to control motor capabilities of the entity and, in other hand, to take into account cognitive capabilities. We also focus our research activity on the virtual environment modeling process. In this field, we integrate, in the modeling process, geometrical information as well as topological and semantic information.

Two transverse topics are also very active:

- **Virtual Reality**: this field deals with some of our research topics such as lighting simulation, animation or simulation. Our approach adresses real industrial problems and proposes new solutions using our research results. The objective is to adapt the simulation of complex systems to the haptic constraints induced by the interaction by human beings.
- **OpenMASK software simulation platform**: the need of integration of our different research activities has produced a real time and distributed Virtual Reality and Simulation environment. This software is distributed according to an Open Source model (see http://www.openMASK.org).

3. Scientific Foundations

3.1. Panorama

The Bunraku team works on the simulation of complex dynamic systems and the need of 3D visual restitution of the results. These results could be producted in real time or in batch, depending on the nature of the simulated phenomena. Our scientific activity concerns the following points:

- motion of dynamic models for animation and simulation: in this field, our work deals with the modeling of physical systems, the control of these systems and all kind of interaction that could occur during the simulation. Special attention is given to contact and collision algorithms.
- behavioral simulation of autonomous entities: this topic concerns both the interaction between entities and the perception, by the entity, of the surrounding environment. The geometrical information is too poor to take into account the potential relationships between a behavioral entity and its static and dynamic environment. In order to provide high level interaction, topological information on space organization and on the objects of the environment is added to data structures.
- lighting simulation: in complex architectural environments, light propagation and interaction with object material generate a big amount of computation using a lot of memory. Our work on this subject concerns the use of a standard workstation or a network of workstations in order to provide the simulation results. This simulation also has to provide tools for the visual characterization of the quality of the results from the human perception point of view.

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.

As for realistic image synthesis, the physically based animation introduces physical laws in algorithms. Furthermore, natural motion synthesis (living beings) needs to take into account complex phenomena such as mechanics, biomechanics or neurophysiology in order to treat aspects like planning and neuro-musculo activation.

The generation of motion for 3D objects or virtual characters needs to implement dedicated dynamic models depending on different application contexts: natural motion simulation, animation for multimedia production or interactive animation.

The mathematical model of the motion equations and the algorithmic implementation are based on the theory of dynamic systems and use tools coming from mechanics, control and signal analysis. The general structure of the dynamic model of the motion is a hybrid one, where two parts interact. The first one is a differential part while the second one is a discrete event system:

$$\frac{dx}{dt} = f(x(t), u(t), t)$$
$$x_{n+1} = g(x_n, u_n, n)$$

In this equation, the state vector x is the concatenation of discrete and continuous state parameters, u is the command vector and t the time.

For example, the contact and collision mechanical computation is performed using an hybrid system. Physically, a collision is a discontinuity in the state vector space (impulse = velocity discontinuity).

In the context, some emerging topics appear:

Automatic model generation: using a high level specification language, the challenge consists in producing both the hybrid dynamic model and the control algorithm.

Identification : a synthetic model is always difficult to produce off-hand. A new method consists in observing real systems using structural and parametric identification tools in order to determine it.

Level of detail : this tendency is essential in order to treat complex models and can be applied to solve geometric complexity but also mechanical complexity.

3.3. Lighting Simulation and 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.

A global illumination model describes the light transport mechanism between surfaces, that is, the way each surface interacts with the others. Therefore, the global illumination model is a key problem when accuracy is needed in the rendering process (photorealism or photosimulation). As global illumination is a computation intensive process, our research consists in making it tractable even for large and complex environments by making use of graphics hardware (GPU) and parallelism.

Another objective is to propose a new navigation system built upon our client-server framework named *Magellan*. With this system one can navigate through 3D models or city models (represented with procedural models) transmitted to clients over a network. Regarding procedural models, their geometry is generated on the fly and in real time on the client side. These procedural models are described using an enhanced and open version of the L-system language we have developed. The navigation system relies on different kinds of preprocessing such as space subdivision, visibility computation as well as a method for computing some parameters used to efficiently select the appropriate level of detail of objects.

To attain realism in computer graphics, two main attempts have been adopted. The first one makes use of empirical and ad-hoc illumination models. The second one makes use of the fundamental physical laws governing the interaction of light with materials and participating media. It integrates characteristics of the human visual system, in order to produce images which are exact representations of the real world. Our work follows this second approach and relies on the real aspects of materials and on the real simulation of global lighting using physics-based reflection and transmission models as well as a spectral represention of the emitted, reflected and refracted light powers. Unfortunately, global illumination is still a demanding process in terms of memory storage and computation time. Our objective is to rely on the radiance caching mechanism and on the performance of the new graphics cards to make interactive global illumination possible even for complex dynamic scenes made up of natural objects such as grass and trees.

In case of real-time remote navigation, transmission and real-time visualization of massive 3D models are constrained by the networks bandwidth and the graphics hardware performances. These constraints have led to two research directions that are progressive 3D models transmission over Internet or local area network and real-time rendering of massive 3D models.

With regard to progressive 3D models transmission, one can suggest the use of geometric levels of detail (LODs). Indeed, as soon as one LOD is selected according to its distance from the viewpoint, the finer LOD is prefetched over the network. In the same spirit, one can select the LOD of 3D objects to be transmitted based on the available bandwidth, the client's computational power and its graphics capabilities. Our work makes use of these two approaches.

As for real time rendering of massive 3D models on a single computer, one can find many solutions in the literature. The most commonly used solution consists in subdividing the scene into cells and computing a potentially visible set (PVS) of objects for each view cell. During walkthrough, only the PVS of the cell containing the current viewpoint is used for rendering. Our system for interactive building walkthrough follows this approach.

4. Application Domains

4.1. Panorama

Application fields of our research mainly concern the activities where intensive relationships exist between the simulation of physical systems and 3D visualization of the results.The concerned application fields are:

- architectural and urban environments
- energy propagation
- virtual actors and biomechanics
- virtual reality and augmented reality

4.2. Virtual Reality

Keywords: *Augmented Reality*, *Virtual Reality*.

Our activity in this field mainly concerns the multi-modality of human interaction. We focus our works on haptic and pseudo-haptic interaction, on local or distant cooperative work in the context of industrial application. We are also concerned by the production of innovative software solutions.

4.3. Virtual actors and biomechanics

Keywords: *Virtual actor*.

Human motion is a very challenging field. We try to increase the knowledge by producing parametric models of human movements. Indeed, by the use of motion capture systems and simulation of our models we can access to internal state of parameters. We could not access to them on real human. Consequently, we are able to produce virtual experiment in order to validate scientific hypothesis on natural motion. We also work on the analysis-synthesis loop in order to produce very efficient motion models with motion blending, real time constraint management, etc.

4.4. Virtual prototyping and physical models

Virtual prototyping deals with the use of simulation results in order to validate specific functional features during the design process. In the field, we use an optimization technique based on evolutionary algorithms and results coming from CAD process.

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.

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 the platform is available as OpenSource software (www.openmask.org).

OpenMASK is a software platform for the development and execution of modular applications in the fields of animation, simulation and virtual reality. The unit of modularity is the simulated object. It can be used to describe the behavior or motion control of a virtual object as well as input devices control like haptic interfaces. 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.

Visualization can be powered by Performer (Sgi) or by OpenSG (Fraunhofer Institute) and a new visualization module using Ogre is under development.

We are also developing new Model Driven Tools to facilitate the building of new OpenMASK applications.

OpenMASK provides an Open C++ API dedicated to simulated object development and execution kernel tailoring. An OpenMASK application is made of kernels and simulated objects.

Main features offered by the execution kernels:

- 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 (on event reception) for simulated objects.
- Communicating:
  - using data flows between simulated objects
  - using signal diffusion in the environment
  - using events between objects
  - thanks to the provided data-types or specialized data-types created for the application
  - 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.

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 or by OpenSG.
- Component extensibility to take new animation primitives into account (available : quaternions, rotations, translations, matrices).
- X11 event or GLUT events captures and owner forwards.
- 2D or 3D picking and subscribers forwards.

Panel of services covered by reusable simulated objects: We provide a set of 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 specialized sounds
- management of VRPN devices
- management of force feedback devices
- physical scene simulation

Model based tools: This year, we are developing a new approach to create the OpenMASK applications. We are interested in using Model Driven Application. The main aim of this approach is to free the user of fastidious coding and to improve the applications. With appropriate tools (Eclipse, EMF,...) we create an editor to edit models of OpenMASK application. This process is completed by a code generator which codes in c++ the modeled objects.

Technology transfer: Our technology transfer initiative is based on industrials partners and supported by 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 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 available on Irix, Linux and Windows systems.

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, Franck Multon [contact], 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 Lab. of Physiology and Biomechanics of Physical Exercise (LPBEM) from University Rennes 2. The first part of this work deals with the reconstruction of captured motion files. It is done offline with 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.

This format is based on a simplified skeleton which normalizes the global postural informations. This new formalism allows the motion to be adapted automatically to a new morphology in real-time (cf figure 1). This is done by taking kinematic constraints into account. This approach dramatically reduces the post production and allows the animators to handle a general motion library instead of one library per avatar. In order to facilitate the design of constraints, we have developed a xml-based language and a friendly user-interface. Hence, a user can add and edit constraints that are intrinsically linked to the motion, such as ensuring foot-contact with the ground, reaching targets for grasping motions...

The second part of the framework provides an animation library which blends several kinematic parametrized models and adapts them to the environment and the avatar's morphology. The library proposed motion synchronization, blending and adaptation to the skeleton and to constraints. 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 introduced in [3]. Using inverse kinetics enables to impose a position to the character's center of mass in order to deal with balance or dynamics (limited to the center of mass mechanical system).

Figure 1. Six characters with different morphologies replaying the same motion that is also adapted in real time to the evolution of the ground

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 also took part of the RIAM project "Semocap" (which ended in 2006) that involves our partner: LPBEM, University Rennes 2. It currently runs on Windows and Linux with different viewers and it has been also integrated in two different software architectures: AVA from the Daesign company and OpenMASK, our own platform. It has been presented in SIGGRAPH 2005 exhibition at the INRIA's booth.

We are currently connecting MKM with the Virtools professional software in VR simulation in order to deal with complex character control in this environment. This development is partially funded by the "Numerical Plant" project of the "system@tic" French competitiveness cluster. 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 : GIAT Virtual Training

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

In the end of 2005, the GVT project, whose context is presented at the “industrial contracts” section, has lead up to the first official release of the GVT software. In 2006, GVT1.0 software has knew its first sale in Industrials contracts.

Our models and engineering developments have been validating by the Giat-Industries quality service. Datas (VRML models, behaviors and scenarii) have been produced on our models by an industrial partner named Virtualis. GVT is using the latest release of OpenMASK and contributing in future releases and functionalities.

The aim of GVT1.0 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, distribution on network, etc.

6. New Results

6.1. OpenMASK: Model based tools

Keywords: *Eclipse*, *MDI*, *Model Driven Engineering*.

Participants: Yves Bekkers [contact], Benoît Chanclou.

We are developing a new approach to create the OpenMASK applications. We are interested in using Model Driven Application. The main aim of this approach is to free the user of fastidious coding and to improve the applications. Actually he has to model the simulated object instead of coding it. This tool starts with the meta-modeling of the OpenMASK application. An application is compounded of simulated objects seen as boxes with inputs, outputs and events exchange. With appropriate tools (Eclipse, EMF,...) we have created an editor to edit models of OpenMASK applications. This process is completed by a code generator which codes in c++ the modeled objects.

So the end-user has to define only the format of the data which are exchanged between objects, the identifier and format of the event and the objects themselves. The code is fully generated for the inputs, outputs, events processing, initialization and configuration, the remaining work for the user is to complete the call-back methods for each listened event and the main method called at the object frequency.

We benefited from these new engineering methods to improve some features of OpenMASK:

- The code helps the user to gain well coding habits.
- The event processing is split in call-back methods instead of a big processing method.
- The code comes with a complete help document.
- The help document shows examples for the configuration file.
- The modeled objects can be stored in a data base to share them with other users.

This first step is followed by a second one, it consists in a generated editor dedicated to the configuration file of the modeled application. This editor generates a well formed file and helps the user to configure the application which he has modeled.

The next steps are to include in the meta-model some other works developed in the team:

- Awareness for object to visualize informations when the user interacts with them.
- Interactivity paradigm between interactor objects and interacting objects.

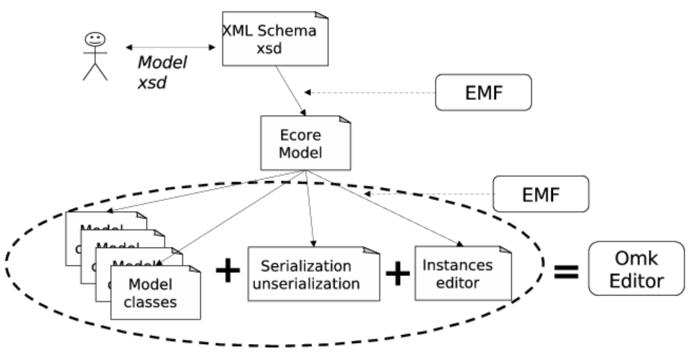


Figure 2. How to build an editor for OpenMASK model (omk) with EMF

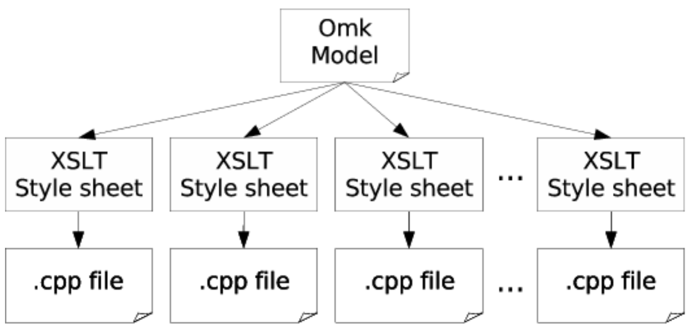


Figure 3. Generated c++ code from an OpenMASK model (omk)

6.2. 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: Jean-Marie Souffez, Georges Dumont.

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 supervised by Georges Dumont, and was partially supported by the RNTL SALOME 2 project. It is based on OpenMASK for the Virtual Reality applications, and SALOME platform for the production of digital mock- ups. The goal is to interactively handle these models in a VR scene, to allow their virtual prototyping. The Phd Thesis has been defended by Jean-Marie Souffez in july 2006 [11].

The Product Development Process has taken benefit from advances in design, simulation and validation processes. Digital mock-ups have thus become too complex to be straightforwardly handled by graphics hardware, the associated mesh and computational results being usually huge and not fitting in- core.

In this context, the use of Virtual Reality as a tool for Virtual Prototyping can provide an easier analysis of meshes and of computational results, by ensuring interactive manipulation of the model. This, in particular, allows to test more parameters for the scientific computations, and ensures easier collaborative design.

As the digital mock-ups are too big to be straightforwardly handled by a single PC hardware, it is necessary to implement a level-of-detail (LOD) framework (see Figure 4 and figure 5), that will control the size of the model at run-time.

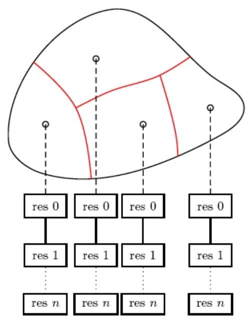


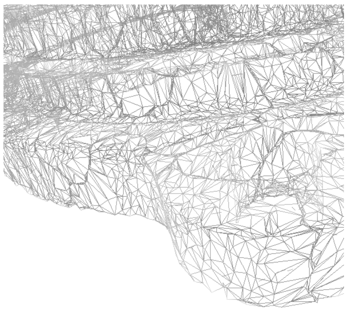
Figure 4. LOD structure.

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.

In comparison to state-of-the-art algorithms, our method is based on a graph-partitioning algorithm (rather than space-subdivision algorithms). The graph partitioning algorithms allow to partition the model with regard to the attributes of the mesh (such as vertex colors, face normals, etc.). This allows to partition the input model with regards to the computational results that are associated to it.

The multi-resolution framework that we have proposed handles both polygon-based and polyhedron-based models. Screen shots from the interactive, out-of-core analysis of meshes are shown in Figures 6 and 7 .


(a)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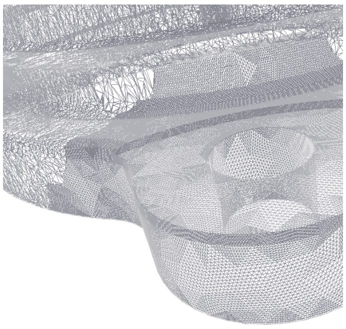
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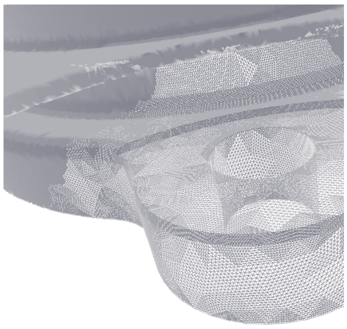
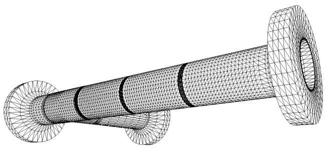

(d)

Figure 5. CylinderHead. (a) Initial model. (b) Zoom in low resolution. (c) Multi resolution view. (d) Hybrid rendering.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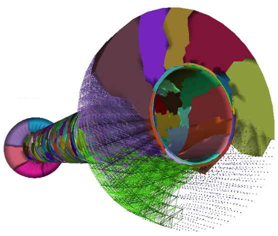
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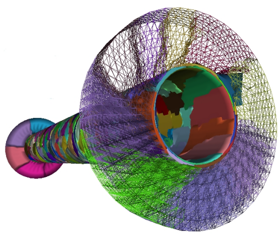

(c)

Figure 6. The model is composed of more than 2 000 000 tetrahedras. (a) Global view. (b) A hybrid rendering mode: the skin of the model is rendered in parts where the mesh is not analyzed (the farthest parts from the user), while the tetrahedras of the analyzed parts are rendered. (c) Another hybrid rendering mode: the user now focuses on the nodes of some parts of the model. Model courtesy of EDF.

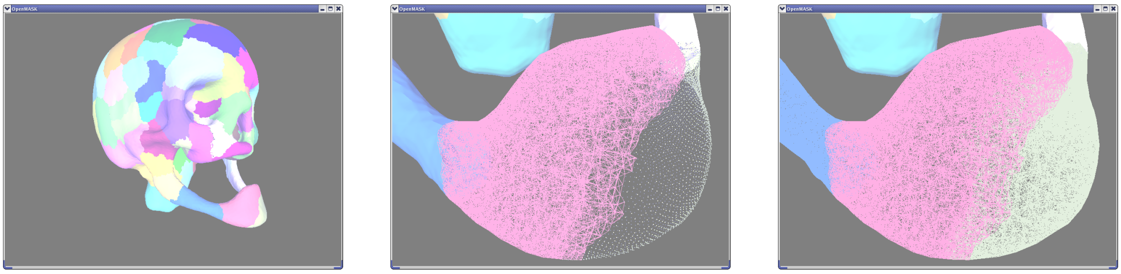


Figure 7. Multi-resolution visualization for skeleton head model of ten millions of tetrahedras and with boundaries resolution adaptation.

The application of the method to volumetric meshes has been published in [60].

6.3. Dynamics-based analysis of adapted motions

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

Participants: Nicolas Pronost, Georges Dumont.

Retargeting and interpolation methods may introduce physical inaccuracies in virtual human animation. We propose a method for evaluating the dynamical correctness of retargeted and interpolated motions generated by an editing method [33]. 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. To study the physical accuracy of the adapted motions, we determine the resulting forces and torques at joints, with a special attention to the ground reaction forces. With this intention, we propose an automatic creation of the biomechanical model of the character upgraded with the masses and inertias of the limbs and the motion mapping on this model. Then using support phase recognition, we compute resulting forces and torques by an inverse dynamics method [58] (see Figure 8).

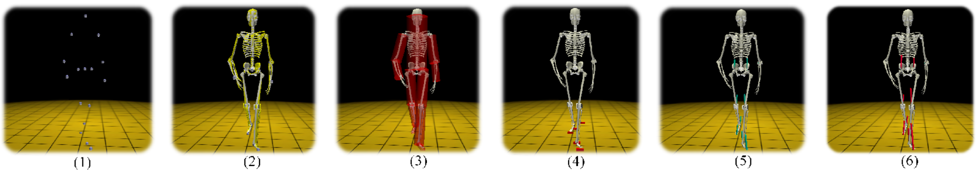


Figure 8. Some steps of our analysis method. From a retargeted and/or interpolated motion (1), our system automatically maps the motion (2) on a mechanical skeleton including masses and inertias information (3). Then we estimate support phases (4), and solve the physical laws, computing resulting forces. We finally validate the motion (5) or not (6) by comparison with literature and experimental data.

The questions we want to answer on the adapted motions are:

- Are the adapted motions physically valid ?
- If so, what are the limits of the method ?
- And are these limits due to the retargeting or to the interpolation ?

To answer the first question, we applied *direct* adaptations, i.e. we apply the retargeting on a known real morphology and we use real data of this character to interpolate the motion. Results show good agreements between the resulting ground reaction forces and the experimental data from force plates measured on the same characters.

To answer the next questions, we evaluate how the retargeting and the interpolation methods change the physics of the motions by using the results of our analysis on artificial and real motions and using literature and experimental data from force plates [57], [56]. Our evaluation relies on the study of several retargeting and interpolation parameters. We thus show the linear relation between the global size of the character and the physics, as well as the importance of the heaviest limbs. We also present the kinematical and dynamical influence of the structure of the model, and the influence of interpolation parameters such as the step size, the motion style and the character velocity. For each parameter, we study these limits and we propose solutions to avoid physical inaccuracies.

The analysis process is automatic, generic and independent of the adaptation method. Here, the process is applied to retargeted and interpolated motions, but it can be used on real motions or edited or blended motions. We present this approach as a post-process for dynamics-based analysis, but the method could be performed in real-time during the adaptation algorithm.

This work forms a part of a soon defended Ph.D. thesis [10]. Future works will focus on extending the validation with more experimental data and overcoming the standard limitation of inverse dynamics methods (uniform distribution of masses, no joint frictions). We also plan to use this work in forward dynamics synthesis in order to correct the motions.

6.4. Interactive Global Illumination

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

Participants: Kadi Bouatouch, Pascal Gautron, Jaroslav Křivánek.

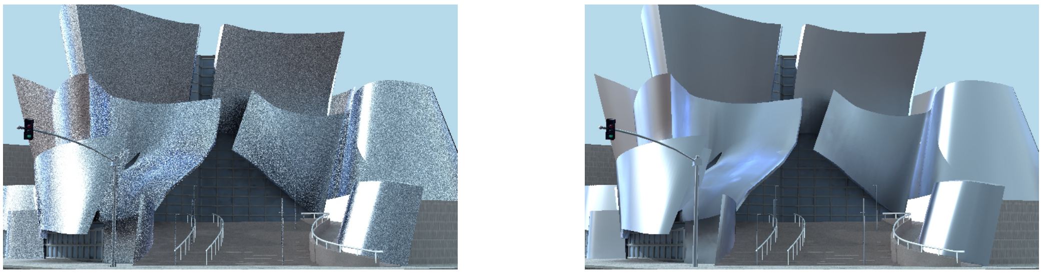
We have designed and implemented a software for interactive global illumination using programmable graphics hardware.

Computing global illumination amounts to solve the rendering equation which is an integral equation. Unfortunately, this equation does not have an analytic solution in general. Consequently, Monte Carlo integration is the method of choice for solving it. However, Monte Carlo integration requires the computation of many samples, which makes it demanding in terms of computation time. Our objective is to propose an algorithm which allows interactive global illumination.

Our approach makes use of ray tracing, Monte Carlo integration and caching. It aims at extending the "irradiance caching" algorithm. Note that this algorithm is based on the observation that the diffuse component of radiance, reflected on a diffuse surface and due to indirect illumination, changes very slowly on this surface. This allows to sparsely sample and cache the incoming radiance, then to reuse the cached samples to estimate the incoming radiance at nearby points. This method is computationally efficient since the sampling is sparse. However this method is limited to indirect diffuse lighting computation.

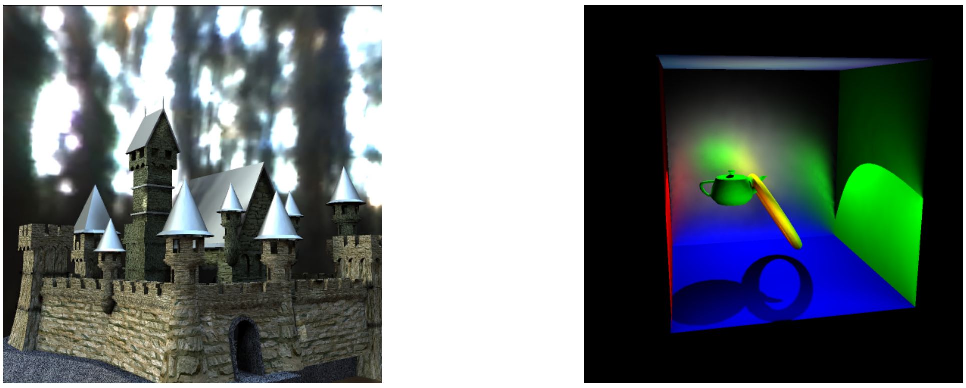
We focus on extending the irradiance caching approach to indirect glossy global illumination. Our algorithm relies on "radiance caching" (cf figure 9). It is based on the caching of directional incoming radiances. We have first designed a new set of basis functions defined on the hemisphere to represent directional incoming radiance and BRDFs. This representation along with a new gradient-based interpolation method are the bases of our radiance caching-based algorithm.

The "radiance cache splatting" algorithm 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 (cf figure 10). Our approach yields an overall speedup of $30 - 40\times$ compared to the Radiance software, considered as the reference for irradiance caching.



Monte Carlo sampling (a) Radiance Caching (b)

Figure 9. Rendering of a simple model of the Walt Disney Hall in Los Angeles. These images have been both generated in approximately 5 minutes, using Monte Carlo importance sampling (a) and Radiance Caching (b). Unlike Monte Carlo importance sampling, Radiance Caching allows to obtain smooth illumination, yielding more realistic results.



Castle (58K triangles) (a) Glossy Cornell Box (1K triangles) (b)

Figure 10. Glossy scenes rendered using our GPU-based renderer and the Radiance Cache Splatting algorithm. The Castle (a) is illuminated by a complex lighting represented by an environment map. The Glossy Cornell Box (b) illustrates the correctness of the reflections obtained using our method. Both images have been generated in approximately 11s at resolution $1000x1000$.

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. Moreover, temporal gradients do not rely on any new, complicated data structure. This method can be straightforwardly included in any existing renderer based on irradiance and radiance caching. Furthermore, our method can be easily implemented using GPUs for improved performance.

6.5. Rendering of natural objects

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

Participants: Kadi Bouatouch, Kévin Boulanger.

We have designed and implemented a software for interactive rendering of natural objects such as grass and trees.

Grass and other natural objects on the Earth's surface make up most of the natural 3D scenes. Real-time realistic rendering of grass (or natural objects) has always been difficult due to the excessive number of grass blades (or leaves, flowers, etc.). Overcoming this geometric complexity usually requires many coarse approximations to provide interactive frame rates when rendering. However, the performance comes at the cost of poor lighting quality and lack of detail. We are interested in developing a grass (and different natural objects) rendering technique (also valid for any natural object) that allows better lighting and parallax effect while maintaining real-time performance. We use a novel combination of geometry and lit volume slices, composed of Bidirectional Texture Functions (BTFs), to achieve the high fidelity requirement. BTFs, generated using a fast pre-computation step, provide an accurate, per-pixel, lighting of the grass, leaves, etc. Our approach combines surface rendering and volume rendering. Levels of detail are also accounted for. Our method allows the rendering of a soccer field, containing approximately half a billion grass blades, with dynamic lighting in real-time (cf figures 11, 12 and 13).

6.6. Subsurface scattering

Keywords: *GPU*, *Subsurface Rendering*, *Translucent Objects*.

Participants: Kadi Bouatouch, Kévin 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. 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 propose a fast surface approximation algorithm to evaluate these distances. Our whole algorithm is implemented on the GPU.

6.7. Modeling and display of virtual urban environments

Keywords: *L-systems*, *Rewriting Systems*, *Virtual urban environments modeling*, *real-time visualization*.

Participants: Kadi Bouatouch, Julien Perret, Stéphane Donikian.

Figure 11. One view of a grass field

Figure 12. View of grass field with other objetcs

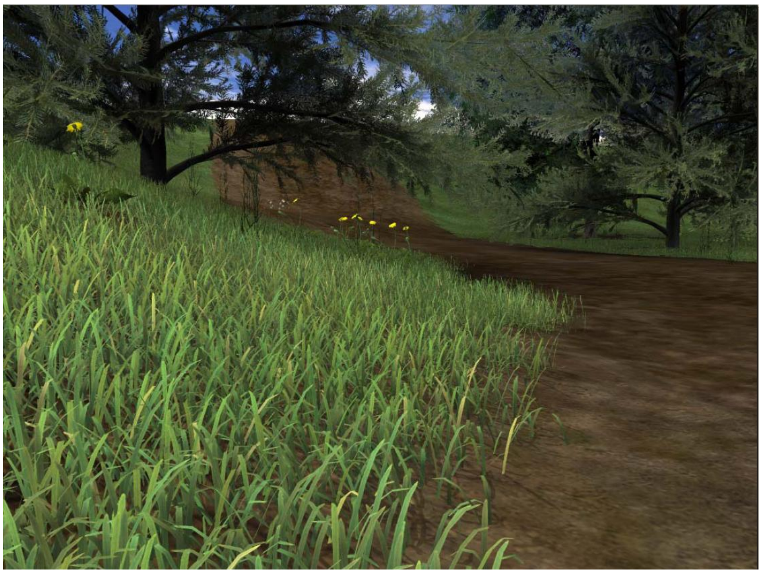


Figure 13. Another view of a grass field

We have designed and implemented a software for creating cities using procedural models based on our new scripting language.

Modeling large virtual environments addresses several issues related to the complexity of the model and the data volume. Indeed, such models are as delicate to acquire or design than to use. In terms of modeling, these models require heterogenous data such as GIS information, terrain elevation, traffic network, buildings geometry, etc. Furthermore, considering the multiple scales in play and the diversity of the objects involved, few modeling techniques are suitable for such a task as designing a virtual city. Moreover, large models suggest large amounts of data. Thus, these models need large storage capacities, are hard to maintain (and/or update), and can be difficult to render in real-time; let alone through a network.

We proposed a functional extention to L-systems, namely FL-systems. L-systems offer a powerful mechanism for biologically-motivated modeling. It has been proved useful for plants, trees and street networks description. Despite numerous extensions, L-systems remain essentially used for plant-modeling purpose. FL-systems have been proved suitable to model urban features such as buildings, street networks, street lamps, etc. This representation is interesting for several reasons. First, as a grammar-based mechanism, it acts as a data compression scheme. It is therefore easier to transfer through a network as well as simple to evaluate in a lazy fashion. Second, it operates as a data amplifier: a single FL-system can generate a large diversity of models if provided different sets of parameters or using probabilistic rules. Finally, it offers a new modeling technique.

We proposed a new caching mechanism for FL-systems: the FL-systems Intelligent Cache. This new cache operates during the rewriting process of an FL-system. Based on dynamic dependancy calculus, this cache takes in account the formal properties of the FL-system using it. This cache is therefore able to compute which rules will generate similar results upon rewriting. While rewriting, it checks in the previously rewritten terms if there is one similar and if so, uses it. This cache has two main goals: it fastens the rewriting process of FL-systems and allows an implicit procedural instancing of objects. The instancing of geometric objects makes the rendering of the scenes faster whereas its implicit nature takes its responsability off the modeler's shoulders.

Such methods are currently being integrated inside a modeling software dedicated to urban environments such as shown in figure 16. (F)L-systems, as well as other rewriting methods allow a novel modeling process.

Figure 14. Subsurface scattering within skin : appearance of veins

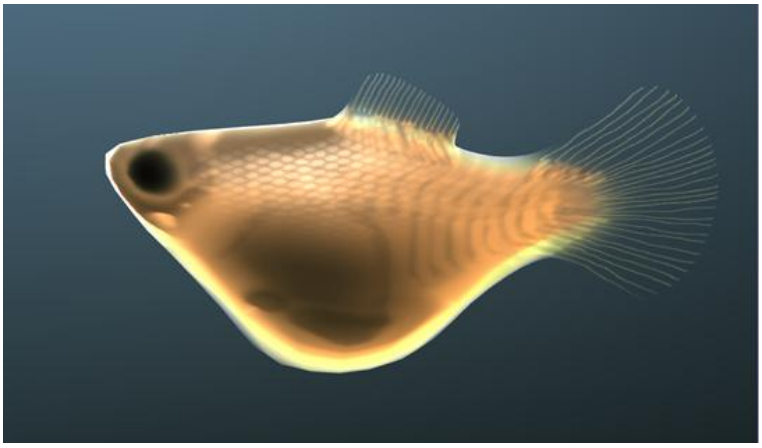


Figure 15. Subsurface scattering within a fish

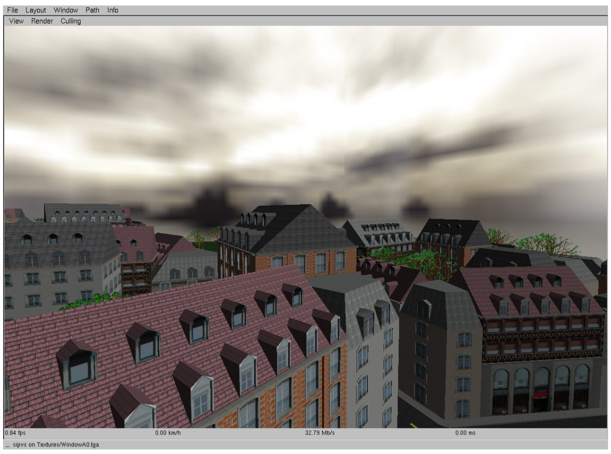


Figure 16. A city model

Furthermore, this multi-scale design process is enhanced by automatic generation capabilities and real-time visualization techniques.

6.8. Interactions within 3D Virtual Universes

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

Participants: Thierry Duval [contact], 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.

During this year, we worked upon:

6.8.1. Architecture for objects interactivity

This work is based on Design Patterns and software architectural models, to allow a good software reuse. These concepts and an associated implementation methodology have been presented this year at thee IHM'2006 conference [44].

6.8.2. Management of the Network Troubles while Interacting within Collaborative Virtual Environments

To visualize differences between a referential and some of its mirrors because of network delay or disconnection, we use an echo object that represents the state of its associated real distant object: the mirror of a referential. An echo has the shape of its associated object but is a little bit smaller and half-transparent so that we can not see it when a simulation is going on normally. When the delay between the referential process and its mirror process is important, we may see a gap between the motion of the referential and the motion of the echo of its mirror (figure 17 (a)), and in case of a disconnection, the echo is frozen on the screen and does not evolve any more. This means that the mirror concerned with this echo is not receiving updates any longer because of the disconnection. We use local objects (a kind of referential that can not have mirrors) to create echoes dynamically. Once a site has detected the loss of another distant site, it enables the creation of local echo objects that appear exactly with the last known states (position and orientation for example) of existing referentials. Only one simulation step time separates the physical disconnection of a site from the creation of associated echoes on other sites, so the loss of the last exact value is not really significant. Echoes may also appear with the current state of some mirrors in the scene, since the dynamic echoes creation system detects also mirrors that have “brothers” (mirrors associated to the same referential) located on a disconnected site. This way, users become aware that their interactions with some objects are not perceived any longer by some other users.

The marker system surrounds some mirror objects by a half-transparent sphere, which visualizes that these marked objects are not holding the last updated values (figure 17 (b)). It marks only the mirrors associated to referentials that exist on a disconnected site. This gives to the user a very specific idea concerning the disconnected sites, and does not charge the scene by undesirable marks.

The echoing and the marking system have been presented in [42].

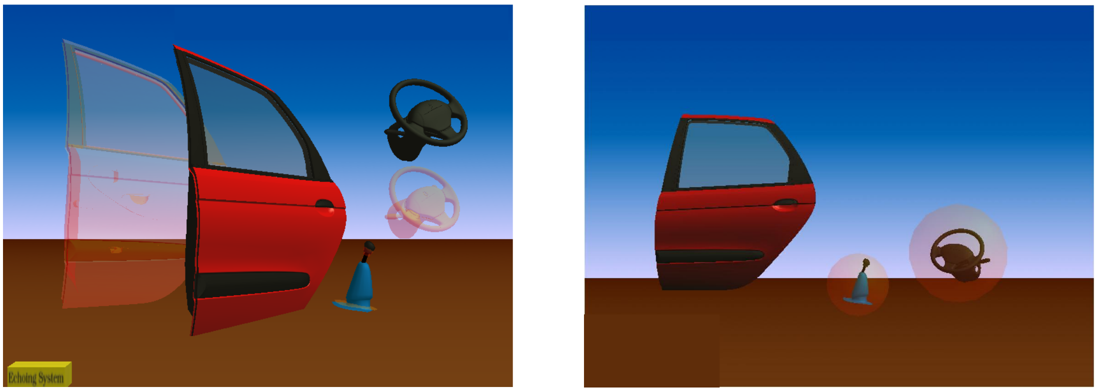


Figure 17. (a) The echoing system and (b) the Marker System

6.8.3. Migration of virtual objects during collaboration

We studied the possibility to make the virtual objects migrate from one process to another during a collaborative simulation.

It can be useful when there are network problems, when we want to interact as efficiently as possible with an interactive object, or simply when we want to withdraw a process without losing the objects it handles.

Distant interactions between a local interactor and a distant interactive object (located on another process on another site) can seem strange to a user because there will be allways a small time lag between the evolution of the interactor and the evolution of the object in interaction with it. This divergence will increase with network latency, which can even lead to unusable interactions if the network latency is too high or not stable enough. So it can be useful to be able to make an interactive object migrate (maybe temporarily) to the same process than the interactor that is controlling it. It is also very useful to make some objects migrate to the process of an interactor, when we know that this interactor will have to interact with them and if we can predict that there will be some network problems during the time of these interactions. Of course, it does not solve network problems during simultaneous multi-user interactions with a shared object.

A first version of migration of virtual objects has been implemented within the OpenMASK kernel, this is detailed in [41].

6.8.4. Evaluation of a new interaction tool for collaborative interactions

we have proposed a new interaction tool to facilitate 3D manipulations of 3D virtual objects, dedicated to immersive interactions.

The idea is to offer end-users a “natural” way to move and rotate collaboratively some virtual objects, allowing several users to grab various parts of an object, and managing their efforts to merge theirs actions to propose new positions and orientations for the interactive object, as illustrated in figure 18.

First we designed and implemented a new software protocol for interaction, then made some experiments to evaluate the efficiency of our new mechanism. The task the users had to realize was to move in a collaborative way one interactive object within a labyrinth. Somes snapshots of these experiments in figure 19, show the physical environment used: the users are immersed in a Reality Center, they can talk together, each of them has its own viewpoint upon the universe and can not see the other user’s viewpoint. As each viewpoint is designed to facilitate the manipulations in a different area of the labyrinth and to make it hard for another area, the two users must absolutely cooperate to manage the task successfully. This work has been presented in [43].

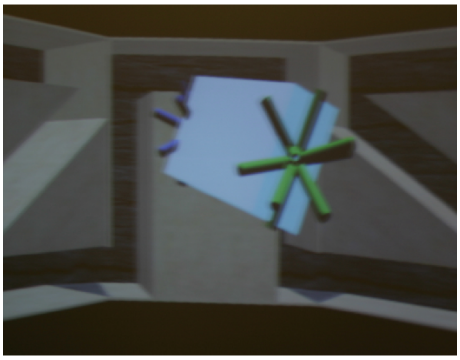


Figure 18. Interactive object grabbed by two users

(a) (b)

Figure 19. (a) Front view of the cooperation (b) The devices used for interaction

The first results have shown that our cooperative paradigm works and is at least as efficient as the more classical collaborative paradigms, we now have to examine more precisely the data collected during the experiments in order to obtain a better validation of its efficiency.

6.8.5. The Immersive Virtual Cabin (IVC)

The objective of the Immersive Virtual Cabin is to make the design and the use of 3D interaction techniques easy, and to make possible to use them in various contexts, either for different kinds of applications, or with different kinds of physical input devices. We have developped a first prototype of the IVC, as described in [40], which is a set of reusable modules within the OpenMASK Collaborative VR development framework.

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

- to navigate within the virtual environment, whatever its size, with the richest navigation functionnalities possible,
- 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 change dynamically its scale, to explore various aspects of the virtual universe, at microscopic or macroscopic levels,
- to integrate various physical workspaces linked to the freedom of move offered by the input (colocalization of the physical input devices) or output devices (display of the physical limits of the IVC: the projection screens).

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.

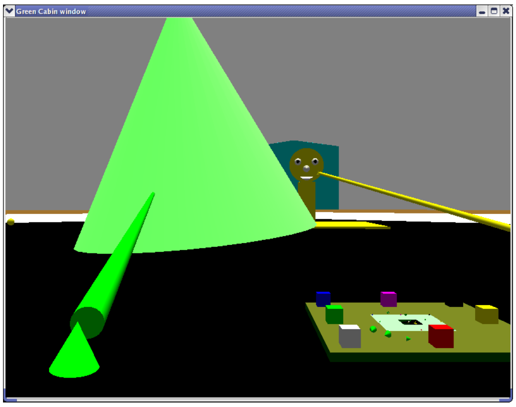
The IVC is adapted to the scale of the user, i.e. the scale of the real world: it is the only way to be able to carry out, if necessary, colocalizations between the real tools and their representation in the virtual scene. It is then necessary to immerse the IVC in the virtual universe. By modifying 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.

We chose to rather adapt the cabin to the scale of the virtual world than adapt the virtual world to the scale of the cabin because this offers the advantage of not modifying the virtual universe as a whole, which is of primary importance for multi-user virtual universes, in which we will find one IVC per user. This way several users can interact simultaneously at different scales in the same virtual universe. A dynamic example of adaptation of the size of the IVC is presented figure 20: the stages a, b and c represent an increase of the size of the green IVC (with its green ray embarked whose support does not change visually at the time of the changes), whose point of view is visualized on the left (a1, b1, c1). These transformations are made whereas this IVC is motionless, they are observed by the yellow IVC, which point of view is visualized on the right (a2, b2, c2).

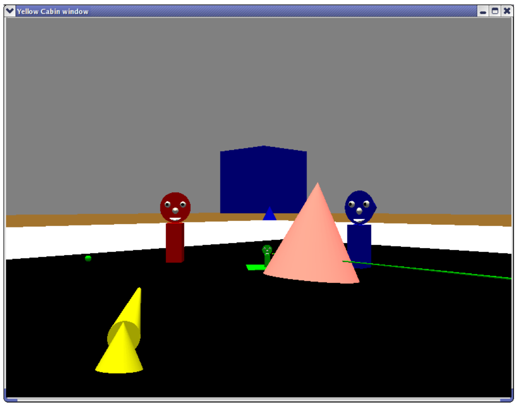
6.8.6. Use of Camera Motions to Improve the Sensation of Walking in Virtual Environments

In this study we have investigated the use of camera motions, in order to improve the sensation of walking in a Virtual Environment.

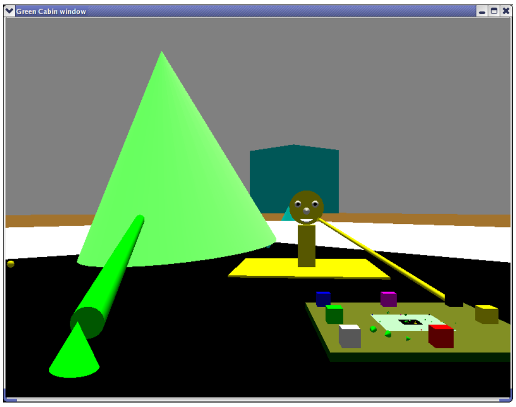
We have first proposed a simple model of camera motion (see Figure 21) that uses: (1) oscillating motions for the position of the camera, and (2) a compensation motion which changes the orientation of the camera and simulate oculomotor compensation to keep a constant focal point when walking (see Figure 21).



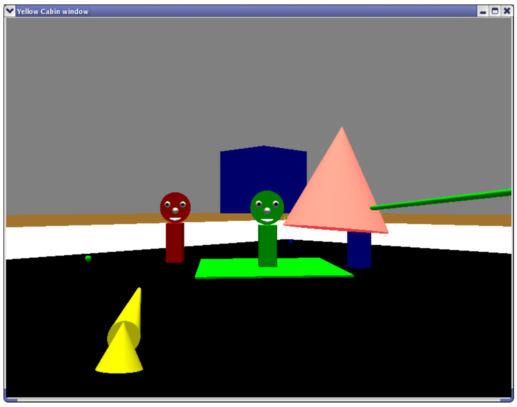
(a1)



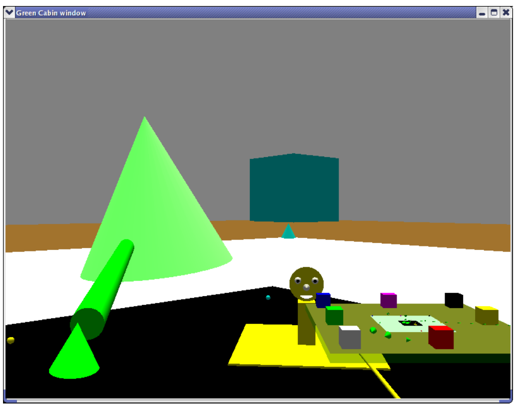
(a2)



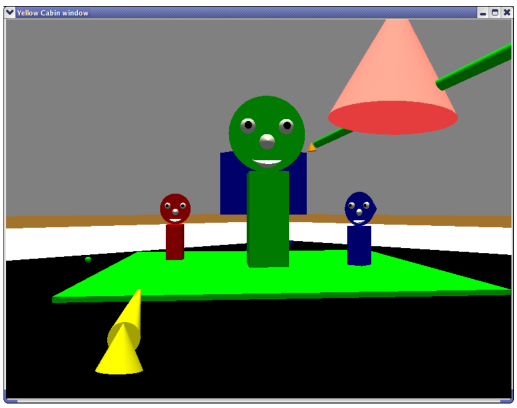
(b1)



(b2)



(c1)



(c2)

Figure 20. scalings of the green IVC which grows at the time of the stages a, b and c.

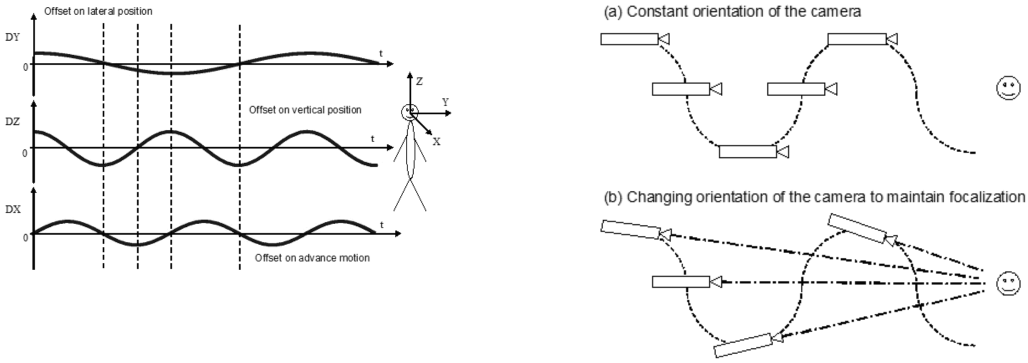


Figure 21. Camera motions to simulate walking in virtual environments

Then we have performed two experiments which were conducted to study the characteristics of our model and the preference of the users in terms of sensation of walking. The first experiment compared the use of oscillating camera motions along the three directions of space. The oscillating motions were all preferred to the control condition (i.e. a linear motion, as if the user was driving a car). Furthermore, the participants preferred oscillating motions along the vertical axis, compared with the two other directions of space. The second experiment was focused on the use of a compensation motion. It showed that on average participants preferred a compensated motion during the walk, as compared with a motion with a constant orientation of the camera. These results are consistent with the way our body and eyes move naturally when walking in real life.

Taken together, our results suggest that camera motions can considerably improve the sensation of walking in virtual environments. Camera motions could be further introduced in numerous applications of virtual reality in which the simulation of walking is important, such as: architectural visits, training simulations, or videogames. This work was presented at IEEE Virtual Reality 2006 [52].

6.9. Haptic Interaction

Keywords: *Bubble Technique*, *Contact*, *Haptic*, *Haptic Hybrid Rotations*, *Spatial Delocation*, *Visual Cues*, *Visuo-Haptic Integration*.

Participants: Anatole Lécuyer, Bruno Arnaldi, Jean Sreng, Lionel Dominjon.

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) perception issues (the influence of spatial delocation on visuo-haptic integration), (2) interaction techniques with haptics (the Bubble Technique and the Haptic Hybrid Rotations), and (3) the use of visual feedback to display haptic (contact) information.

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. A study of the influence of **spatial de-location** on the perceptual integration of vision and touch in Virtual Environments,
2. **the Bubble Technique**: a novel interaction technique for object manipulations in large VE using haptic devices with limited workspace,
3. **the Haptic Hybrid Rotations**: an extension of the Bubble technique to handle large rotation motions in VE using again haptic devices with limited rotational workspace,
4. **Visual Cues of Contact**: a set of visual cues that display contact information in order to improve assembly/maintenance simulations.

6.9.1. Influence of spatial delocation on the perceptual integration of vision and touch

How do we perceive objects when what we see and what we touch is not at the same place? We studied in a Virtual Environment (see Figure 22) the bimodal integration when the visual and haptic percepts are de-located. To manipulate the spatial location of the visual and haptic percept we used a virtual reality apparatus known as “fish-tank”: the participants manipulated an object while looking at its virtual representation reflected by a mirror located in between the eyes and the hand (screen 2). Using stereovision we created the illusion of spatial collocation of the visual and haptic percepts. We compared this collocation situation to a de-location situation in which the visual information was provided by a computer monitor located on the left side of the hand workspace (screen 1). Six participants were asked to judge the rotations of a handle grasped with the dominant hand and watched on the computer screen or in the mirror.

We mainly found that in the de-location case the visual information becomes even more dominant. In other words, in the integration process the weight of vision becomes stronger. Actually, in our experimental setting and for our task, vision overwhelmed haptic almost completely. We conclude that for spatial tasks, de-location of visual and haptic percepts seems to prevent visuo-haptic integration and favors the dominant sense.

On the whole, our results on the judgment of a handles rotation imply that even if the overall performance may not be significantly affected by the spatial de-location of the visual percept, the natural dominance of vision over touch is greatly increased. The designers of teleoperation systems may relate these findings to the task-specific relevance of the two sensory channels. For instance, if the contribution of touch is important for the task, great efforts should be undertaken to collocate as much as possible the visual and haptic percept. In this way the haptic weight would not be penalized. On the other hand, suppose the designer is making use of a low-quality haptic device. In this case the interest may be to contain the limitations of the haptic feedback. Then the usual spatial de-location of teleoperation systems may be of no concern or could be even exaggerated. As a result, the user will rely more on vision.

These results were published in Presence [16]. This work was achieved as an external collaboration with CPNI Lab., University of Angers.

6.9.2. The Bubble technique

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 23). The haptic workspace is displayed visually using a semi-transparent sphere (looking like a bubble) that surrounds the manipulated cursor. When the cursor

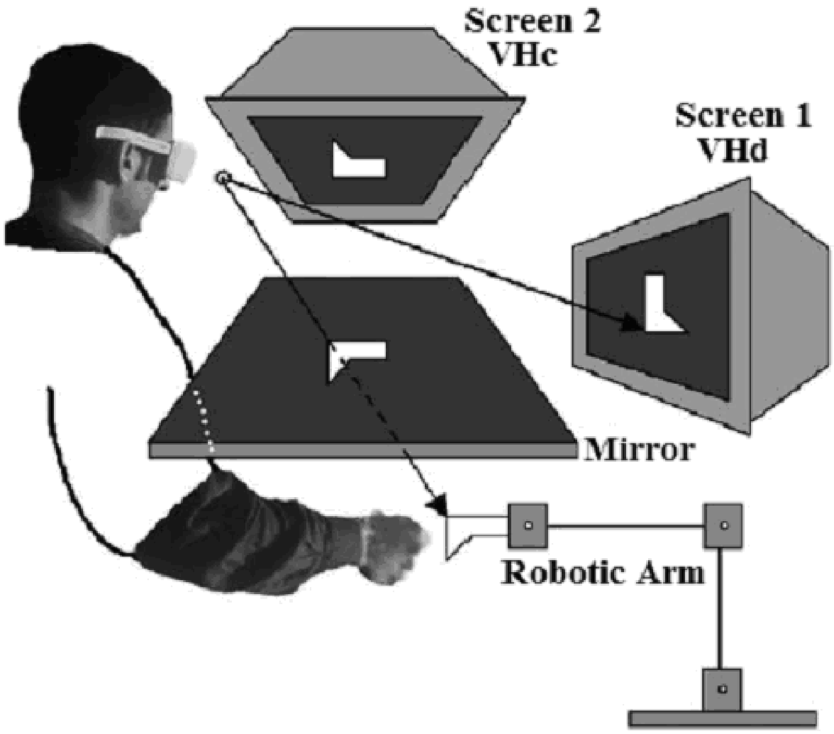


Figure 22. Experimental apparatus used in [16].

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.

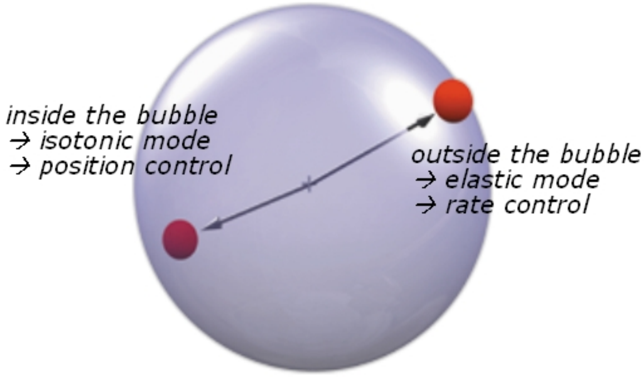


Figure 23. Concept of the Bubble technique

We have conducted an experiment to evaluate the Bubble technique and compare it with two other classical candidates aiming at interacting with large virtual environments using haptic devices with limited workspace: the Scaling technique and the Clutching technique. In this experiment, participants were asked to paint a virtual model as fast and as precisely as possible inside a CAVE, using a “desktop” haptic device. Our results showed that the Bubble technique enabled both the quickest and the most precise paintings. It was also the most appreciated technique.

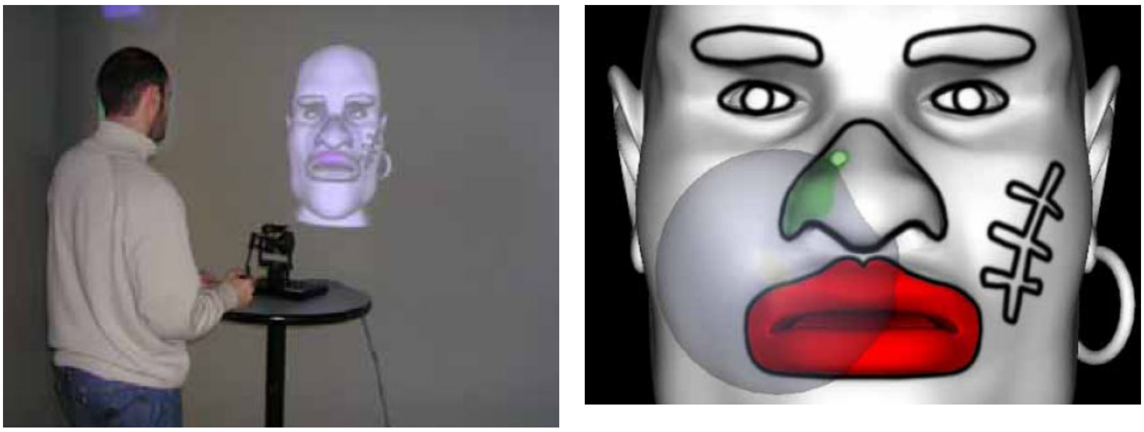


Figure 24. Bubble technique: Experimental Set-Up

These results were published in Lecture Notes in Computer Science [17] and presented at Computer Graphics International Conference 2006. This work was achieved as an external collaboration with CPNI Lab., University of Angers. The Bubble technique will be available in the next release of the VIRTUOSE API, the commercial haptic programming interface of Haption Company.

6.9.3. The Haptic Hybrid Rotations

As an extension of the Bubble technique, we have developped a new 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 25). 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.

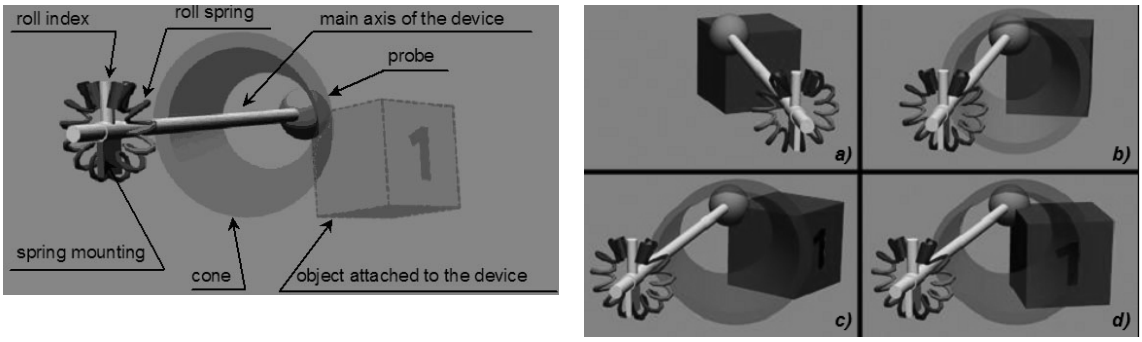


Figure 25. The Haptic Hybrid Rotations technique

To evaluate the performance of haptic hybrid rotations, we have conducted an experiment that consisted in building a pyramid made of several cubic bricks using a given interaction technique chosen among three different candidates (haptic hybrid rotations vs. classical scaling or clutching). Participants were asked to perform the task as precisely as possible. The performance of participants was recorded in terms of task completion time and quality of the final pyramid. Our results showed that haptic hybrid rotations were both the fastest and the most appreciated technique for the proposed experiment.

This work was published at IEEE Virtual Reality 2006 [39]. It was achieved as an external collaboration with CPNI Lab., University of Angers.

6.9.4. Visual Cues of Contact

The geometry of industrial virtual mock-ups is generally very complex and the manipulation of objects during assembly/maintenance simulations may lead to situations of multiple contacts. In a situation of multiple contacts, the manipulation becomes very difficult since the manipulated object is stopped at the level of several contact points. In such case, the force feedback of a haptic device provides global information of force which can not be easily used to extract the multiple information of local contacts.

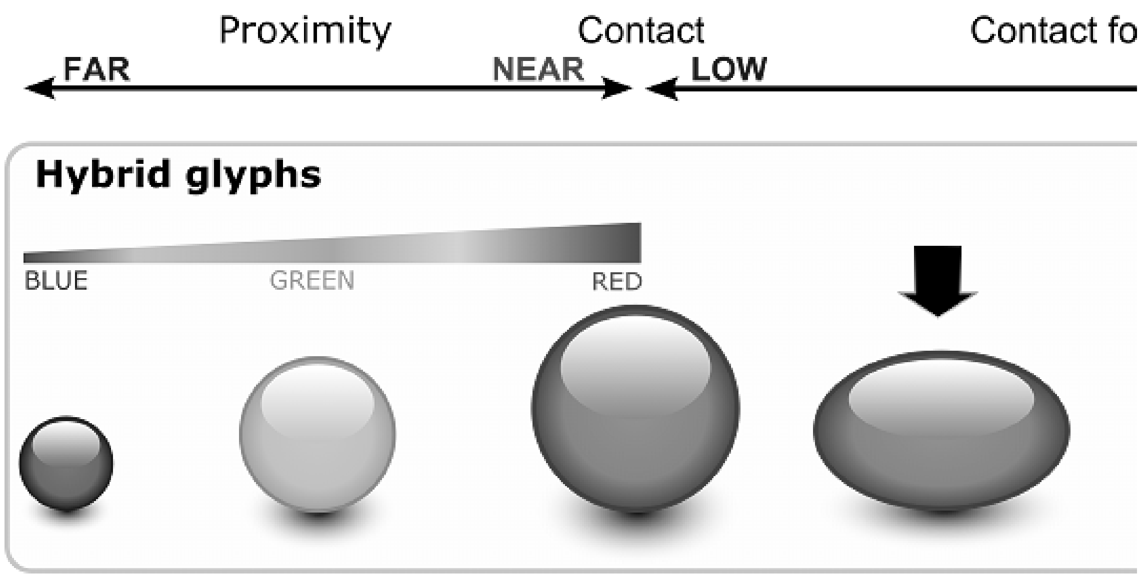


Figure 26. Glyph of contact

Therefore, we have proposed a set of visual cues which are designed to display information of proximity, contact and effort between objects in virtual environments. It encloses the apparition of glyphs (arrow, disk, or sphere) when the manipulated object is close or in contact with another part of the virtual environment. Visual effects such as color change, size change, and shape deformation are applied to the glyphs, as a function of proximity (distance between objects) or amplitude of contact forces (see Figure 26). Light sources are also added at the level of the contact points.

A preliminary evaluation has been performed in which participants could give their preference concerning the different visual cues during a complex assembly simulation (see Figure 27). This informal evaluation suggested that that the visual glyphs and their associated visual effects seem useful to inform about distances (proximity between parts) and contact forces, while light sources seem appreciated to focus the attention of the user on the contact areas.

This work was published at IEEE Transactions on Visualisation and Computer Graphics [35]. It was achieved as an external collaboration with CEA LIST.

6.10. Brain-Computer Interaction in Virtual Reality

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

Participants: Anatole Lécuyer, Fabien Lotte, Yann Renard, Mingjun Zhong, Fabrice Lamarche, Bruno Arnaldi.

Brain-Computer Interfaces (BCI) consist in using the cerebral activity of a person to control directly a machine or a computer. In this section we describe our recent results in the field of BCI and Virtual Reality.

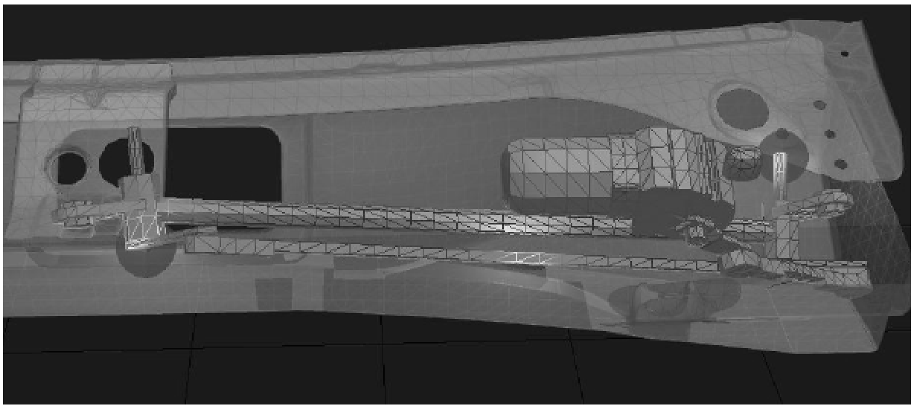


Figure 27. Visual Cues of contact in use

When the physiological activity of the brain (e. g., ElectroEncephaloGram, Functional Magnetic Resonance Imaging, etc.) is monitored in real-time, feedback can be returned to the subject and he/she can try to exercise some control over it. This idea is at the base of research on Neurofeedback and Brain-Computer Interfaces (BCI). Indeed, Brain-Computer Interaction consists in using the cerebral activity of a person to control directly a machine (e.g. a robot, a computer, or a Virtual Reality simulation).

Hereafter, we describe our recent results obtained in the field of BCI and VR: (1) a virtual environment called OpenViBE for the visualisation in virtual reality of the whole brain activity in real time, (2) a technique to improve denoising of EEG data using Independant Component Analysis (ICA), (3) a technique to enhance extraction of cerebral features by using spatial filters and electromagnetic inverse solutions, and (3) a technique to classify cerebral activity based on Fuzzy Inference Systems (FIS).

6.10.1. The Open-ViBE platform

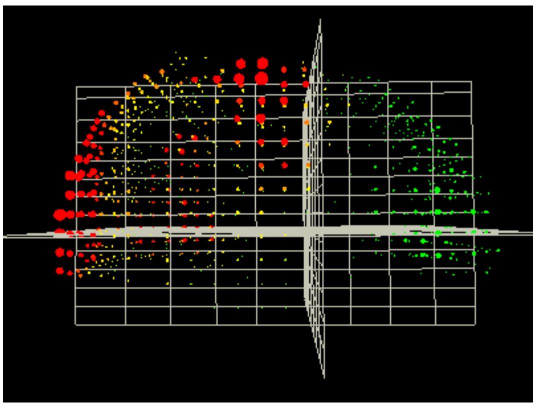


Figure 28. Brain activity visualization with a solution space restricted to the cingulate gyrus.

We have developped Open-ViBE (Open Platform for Virtual Brain Environments) : a general purpose platform for the development of 3D real-time virtual representation of brain physiological and anatomical data. Open-ViBE is a flexible and modular platform that integrates modules for brain physiological data acquisition, processing, and volumetric rendering.

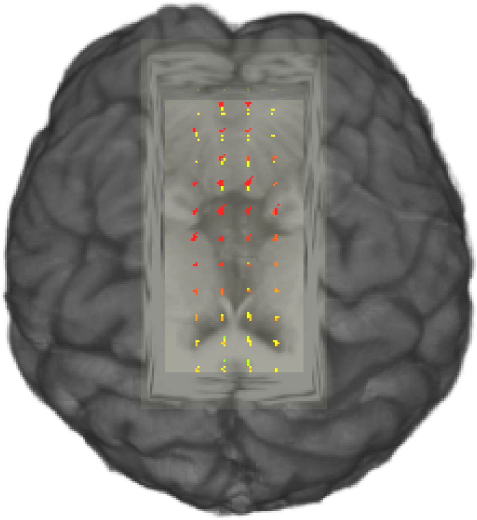


Figure 29. 3D texture rendering of individual MRI (T1) slices. Part of the brain is clipped by a parallelepipedic transparent object allowing the user to visualize the cingulate gyrus. The brain is seen from the top.

When input data is the electroencephalogram, Open-ViBE uses the estimation of intra-cranial current density to represent brain activation as a regular grid of 3D graphical objects. The color and size of these objects co-vary with the amplitude and/or direction of the electrical current. This representation can be superimposed onto a volumetric rendering of the subject's MRI data to form the anatomical background of the scene. The user can navigate in this virtual brain and visualize it as a whole or only some of its parts (see Figure 28 and 29). This allows the user to experience the sense of presence ("being there") in the scene and to observe the dynamics of brain current activity in its original spatio-temporal relations.

The platform is based on publicly available frameworks such as OpenMASK and OpenSG and is open source itself. In this way we aim to enhance the cooperation of researchers and to promote the use of the platform on a large scale. This work is related to the Open-ViBE RNTL Project (see Section 7.3).

6.10.2. Automatic EEG denoising using Independant Component Analysis

Brain-Computer Interfaces using electroencephalogram (EEG) has received great attention due to its potential applications. However, the EEG signals are usually contaminated by ocular and muscle artifacts. These artifacts must be detected and eliminated automatically for the use of BCI.

Most of the current automatic artifact removal methods based on independent component analysis (or blind source separation) are restricted to eliminating ocular artifacts. We have proposed a novel artifact removal method based on blind source separation for automatically eliminating both ocular artifacts and the muscle artifacts located in frontal and temporal locations [66].

Our experimental results showed that the proposed method can automatically eliminate the ocular and muscle artifacts, and outperforms the state-of-the-art method in literature in terms of EEG reconstruction quality. This work was published as an IRISA technical report [66] in which more details on the technique can be found.

6.10.3. Classification of movement intention by spatially filtered electromagnetic inverse solutions

In this work, we coupled the standardized low-resolution electromagnetic tomography (sLORETA), an inverse solution for electroencephalography (EEG) and the common spatial pattern, which was there conceived as a data-driven beamformer.

This technique was evaluated and used to classify the benchmark BCI (Brain Computer Interface) competition 2003, data set IV. The data-set was from an experiment where a subject performed a self-paced left and right finger tapping task.

Available for analysis were 314 training trials whereas 100 unlabeled test trials have to be classified. The EEG data from 28 electrodes comprised the recording of the 500 ms before the actual finger movements, hence represented uniquely the left and right finger movement intention. Despite our use of an untrained linear classifier, and we extracted only one attribute per class (see Fig. 30), our method yield accuracy similar to the winners of the competition for this data-set.

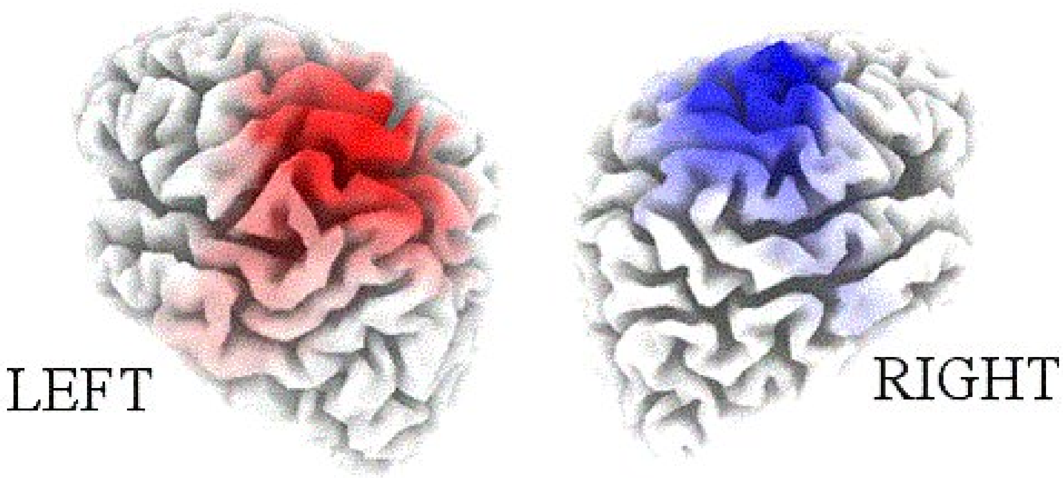


Figure 30. Two features extracted from the brain activity : left (in red) and right (in blue) motor areas.

The distinct advantages of the approach we proposed are the use of an untrained classifier and the processing speed, which make the method suitable for actual BCI applications. The proposed method is favourable over existing classification methods based on EEG inverse solution, which either rely on iterative algorithms for single-trial independent component analysis or on trained classifiers. This work was published in the journal *Physics in Medecine and Biology* [15].

6.10.4. The use of Fuzzy Inference Systems for Classification in EEG-based Brain Computer Interfaces

In this study we introduced the use of a Fuzzy Inference System (FIS) for classification in EEG-based Brain-Computer Interfaces. We implemented a FIS algorithm and compared it, on motor imagery signals, with three other popular classifiers, widely used in the BCI community.

Our results showed that FIS outperformed a Linear Classifier and reached the same level of accuracy as Support Vector Machine and neural networks. Furthermore, FIS algorithms have two additionnal advantages:

they are readable, which means we can easily interpret what they automatically learnt and easily extensible, i.e., we can easily add them *a priori* knowledge. All these advantages make FIS classifier suitable and useful for real-time BCI design.

This work was published and presented in the *Third international Brain-Computer Interfaces workshop and training course 2006* [51] and at the "Journées de l'Association Française de Réalité Virtuelle" [50].

6.11. 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, 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].

However, in those previous works, the method was not able to accurately understand the process used by the goalkeeper to choose his parade. This year, we have adapted this framework in order to focus on the problem of perception. The main problem is to accurately understand how the goalkeeper perceive its environment and especially the gestures of the opponent. In collaboration with LPBEM of University Rennes 2 and UMR 6152 "Mouvement et Perception" in Marseille, we have designed a protocol to separate various kinds of visual elements that could be used by the goalkeeper. For example, if we hide the ball, does it change the goalkeeper's anticipation?

As this protocol was focused on perception, we have improved the previous framework by changing the parameters of the virtual camera according to the instantaneous displacement of the goalkeeper's head. The Vicon-MX (product of Oxford Metrics) was used to capture the position and orientation of the head in real-time. Another important point was to determine if the goal actually intercepted the ball's trajectory, which was not possible in the previous framework. Again, the motion capture data are processed in real-time to check the collisions between the goalkeeper's body and the trajectory of the ball, as shown in figure 31.

Then the protocol was composed of various faked virtual throws. Three main kinds of modifications are applied on the animation of the thrower:

- the ball is hidden during all the sequence but the entire character is rendered,
- the thrower is hidden whereas the ball is displayed,
- the sequence is stopped before ball release, with various time delays.

All those modifications were supposed to better analyze the perception of the subject during duels. They were designed in collaboration with LPBEM of University Rennes 2 and UMR 6152 "Mouvement et Perception" in Marseille. The preliminary results demonstrate that displaying the ball or not is not an important point. On the opposite, not displaying the thrower really affects the goalkeeper's anticipation skills. Moreover, we are currently studying the time at which the subjects actually take information during the opponent's throw by determining the time delays before ball release below which the subjects change their anticipation skill.

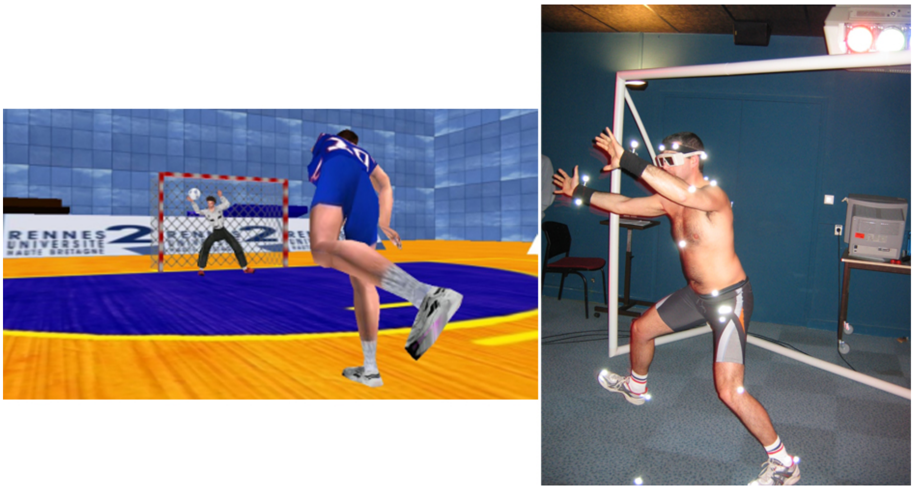


Figure 31. Left part shows the goalkeeper avatar intercepting the ball thrown by a virtual opponent and collision checking is running. Right part shows a subject that was captured during the experiments.

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 (LPBEM of University Rennes 2) and neuroscientists (UMR 6152 "Mouvement et Perception" in Marseille and Queen's University of Belfast).

6.12. Real-time animation of virtual humans with motion capture

Keywords: *Human Motion*, *Interactive Animation*, *Motion Capture*.

Participants: Franck Multon, Richard Kulpa, Nicolas Pronost, Georges Dumont, Bruno Arnaldi.

Past years, we proposed a new formalism to model human skeletons and postures. This formalism is not linked to morphology and allows very fast motion retargeting and adaptation to geometric constraints that can change in real-time. Captured motions are consequently stored using this formalism. 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.

This solver offers inverse kinematics [3] and inverse kinetics [4] capabilities. 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. Moreover, we also introduced the control of the center of mass position in this algorithm (see figure 32). 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.

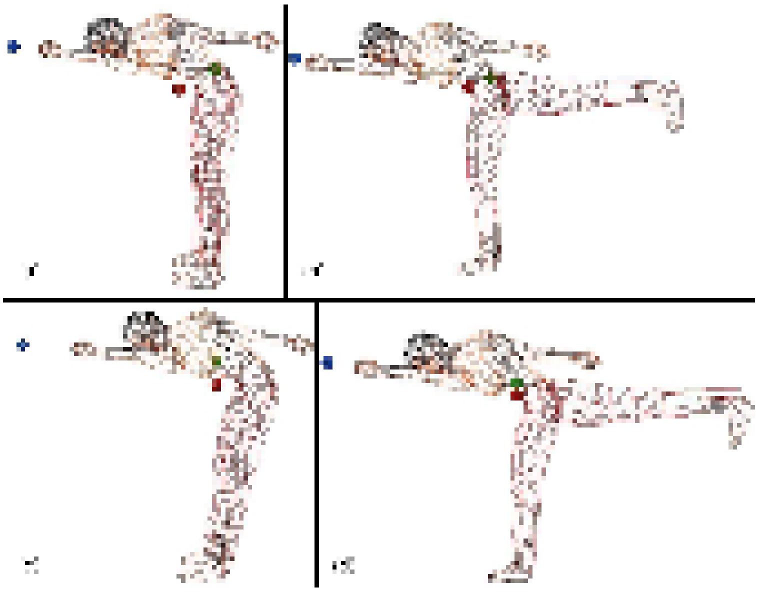


Figure 32. a) grasping without inverse kinetics. b) inverse kinetics has no high priority; the left leg is used to counterbalance the upper-body and the constraint imposed to the wrist is not verified. c) inverse kinetics has high priority but only the root is translated and the constraint is still not 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.

The solver described above can obviously deal with captured motions but it is also able to deal with gestures calculated by other modules. Indeed, this solver is embedded in the MKM software library (cf paragraph 5.3) which also offers motion synchronization and blending. Hence, the solver can be used after motion blending is performed, by taking into account priorities associated to actions [6].

We are currently studying how taking dynamics and style into account. For dynamics, we have proposed to focus on the center of mass system which dynamic equation of motion are simpler than those for an entire skeleton. The goal is to ensure that the character verifies the essential laws of motion, such as following a parabola during the aerial phase and avoiding accelerating more than gravity when decreasing the center of mass' height. Hence, with such dynamic limitations, it is possible to predict how a jump should be adapted to new constraints, such as jumping higher or lower. This approach is not limited to the aerial phase but also provides methods to predict how the preparing contact phase should be adapted. We are currently working on taking the angular momentum into account (in collaboration with Taku Komura from Edinburgh University). For all those contributions, our main goal is to propose alternatives to full-dynamics simulation or interpolation into a database, as currently proposed in the literature. As a first step, we have proposed to analyze accurately the relations between inverse and direct dynamics for locomotion. This work consists in defining a framework to perform inverse dynamics on full-body motions and to try to directly simulate a numerical skeleton with the resulting forces and torques. We have shown that our framework is able to reproduce accurately a real motion by comparing simulation to experimental data. We now want to analyze how the forces and torques are adapted to new skeletons, with different morphological data.

For style, we are working in collaboration with VALORIA, from University of South Britany. The goal is to automatically extract style from a database of expressive motions. To this end, we analyze time alignment of the same motion but performed with various styles. The goal is to extract operators that are able to change the time-scale of a neutral motion in order to make it convey another style. We have applied it on the French Sign language by analyzing the whole-body gestures together with the motions of the hands. To deal with such multidimensional data, we have developed a new method to encode motion (using weighted Principal Component Analysis) and to retrieve time alignments (thanks to an adaptation of the Dynamic Time Warping algorithm).

Future works will focus on extending these two approaches in order to deal with more generic constraints (dynamic and style constraints). Those approaches were developed separately and we now wish to gather those results in the MKM software.

6.13. $2D^{1/2}$ informed spatial subdivision scheme

Participant: Fabrice Lamarche [contact].

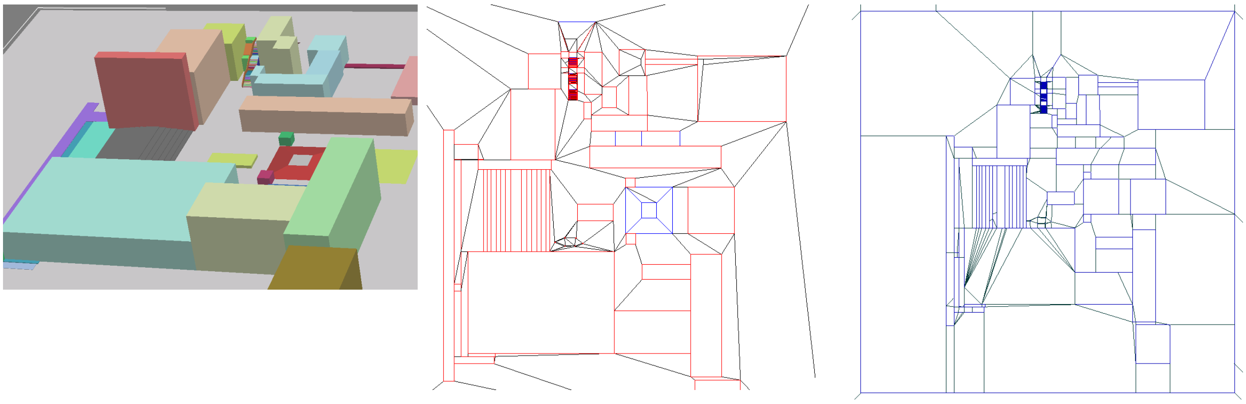
Navigation inside virtual environments has a key role in behavioural animation of a virtual human. This process is continuously used for several sorts of interactions (moving to take something, to watch something...). Navigation and path planning are based on a suitable representation of the 3D database in a form enabling path planning and collision avoidance with static obstacles. But a suitable representation of the geometry is not sufficient as a part of the behaviour is related to the semantic of the environment. Most of time, 3D environments are modeled using well known 3D modelling tools such as 3DS Max, Maya and others. Such environments are not informed neither well organized to be directly used in the field of behavioral animation. That is why we propose a model of $2D^{1/2}$ spatial subdivision, enabling navigation and path planning on unflat surfaces while describing the semantic of the different zones.

Instead of conceiving a dedicated tool constraining designers, we propose to label the 3D objects with their name and type in order to inform 3D environments. This information will be used as a key to access a typed database enabling the extraction of semantic information related to the object.

In order to handle navigation and path planning on non flat surfaces, we propose a $2D^{1/2}$ spatial subdivision scheme. Starting from the $3D$ database (Cf. fig. 33 (a)), two maps are created:

- The $2D^{1/2}$ map (Cf. 33 (b)) is an exact decomposition of the environment into convex cells. Borders of those cells correspond to a change of slope, a step, a bottleneck, a change of semantic type or $3D$ object name. This map is used to handle low level navigation: determining the height associated to a footprint, computing visibility information. It also links cells to semantic information by keeping identifiers related to the objects of the $3D$ database. This way, virtual humans can easily access the semantic information related to the environment they evolve in.
- The 2D map (Cf. 33 (c)) is a simplification of the $2D^{1/2}$ map. In this map, borders of convex cells represent a change of semantic type, a step or an identified bottleneck. This map simplifies the previous one by merging cells with similar semantic thus reducing the number of cells used during path planning.

Semantic information is stored inside an object oriented database (we intensively use notions of classes and inheritance). This database contains two types of information: semantic information related to the environment and archetype description. The semantic information associates objects types to their related information. The archetype database contains a hierarchical description of types of agents navigating inside the virtual world (pedestrians, cars?). In order to correlate archetypes to their respective navigation zones, a relational system is provided. It associates archetypes to types of zones in order to specify their navigation behavior (preference, cost?). As types of zones and archetypes are described using inheritance notions, instantiation of relations



(a) (b) (c)

Figure 33. Spatial subdivision example: (a) 3D world, (b) 2D1/2 map, (c) 2D map

also use this property in order to provide a system enabling a concise and generic description. For example, if humanoids can navigate on sidewalks and if a crosswalk inherits from sidewalk, a relation between humanoid and sidewalk will automatically take the crosswalk into account during path planning and navigation. Thanks to this information, we are able to generate agent oriented path planning graphs used to create more realistic navigation behaviors. This information is also useful to focus agent attention to relevant zones i.e. zones they navigate in.

Thanks to this model, semantic information can easily be associated to the geometry of the environment. The spatial subdivision process, by keeping this information and organizing geometry, enables a rapid integration of virtual humans inside complex and structured environments containing necessary information to handle realistic navigation. Actually, this system is used to handle navigation, but future works will focus on creating a relation between the environment and the BIIO model (cf paragraph 6.15), in order to provide a full framework enabling fast integration of behavioral simulations in informed environments.

6.14. Topologic and semantic abstraction

Participant: Fabrice Lamarche [contact].

Previously, we presented our work on the $2D^{1/2}$ informed spatial subdivision scheme (Cf. section 6.13). This spatial subdivision subdivides the environment into typed convex cells. In order to plan a path in such environments, a cell graph in which a node represent a typed cell and an edge represent a passage from one cell to another can be used. Inside large and complex environments (such as a city for example), such graphs can be very large. The size of such a graph has an impact on path planning time. Moreover, the type associated to each cell is used by the agent in order to express preferences on navigation zones (for example, avoid interior zones and roads while preferring walking on sidewalks, pedestrian crossings, ...). Depending on the agents and their goals, those preferences will defer at runtime. The aim of this work is to provide an abstract representation of path planning graphs, taking into account agent preferences while providing a compact representation, well suited for abstract reasoning and enabling fast path planning.

The figure 34 presents a simple example of a cell type hierarchy and an associated cell graph. By coupling the cell graph structure with the cell type hierarchy, we are able to generate a hierarchical representation of the environment topology. A first example of abstraction is showed in figure 35. This is our first abstraction level which consists of grouping cells into zone of same typology. This first abstraction level simplify the environment structure by reducing the number of considered cells but also enables the detection of topological relations such as enclosing for example. The abstraction hierarchy of cell type is then used to guide the computation of abstraction levels. For example, in the graph of figure 35, connex cells of type shop, subway station and tunnel will be grouped as interior zones. Once topological and semantic abstraction levels are computed, an agent can query a graph representing the fact that it prefer avoiding interior zones and vehicles ways while preferring walking on pedestrian ways. A graph related to this example is presented fig. 36. This graph contains an abstract and compact view of the environment, centred on zone typologies interesting the agent. While navigating or reasoning, the agent can then refine this abstract view by querying local or global refinements on cell types or graph structure.

This model provides multi level views of the environment agents are navigating in. A specific view can be generated for each agent, depending on its goals and needs. This way, an agent can retrieve abstract and compact views of the environment, containing pertinent information for the involved decision process. The hierarchical structure of the representation is adapted to hierarchical decision processes, while enabling precise queries and local refinements, enabling the description of complex reasoning processes on the environment topology. It also facilitates the connexion with high level spatial reasoning processes trying to mimic human cognitive maps and spatial reasoning.

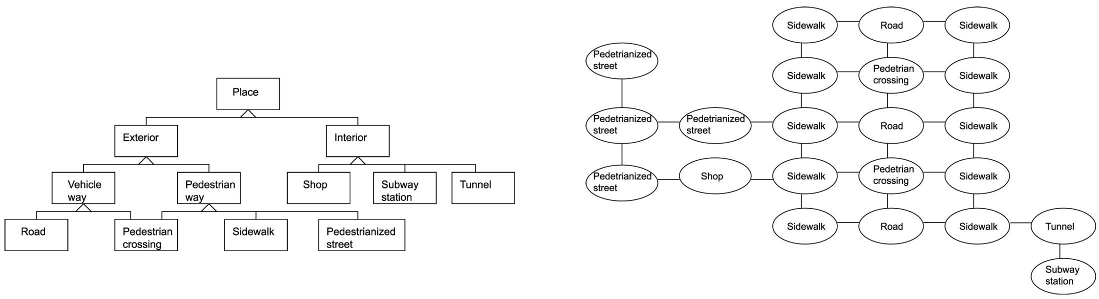


Figure 34. A cell type hierarchy and an informed cell graph

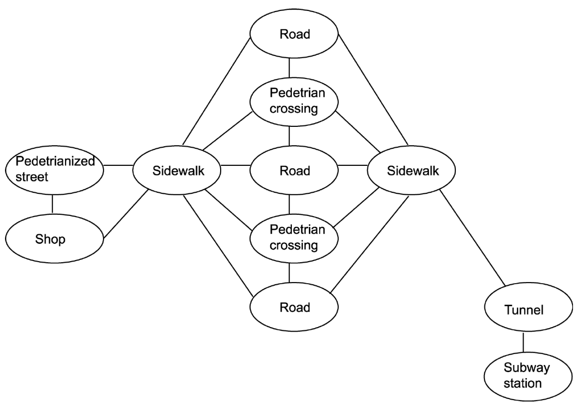


Figure 35. A first topological representation of the environment of figure 34

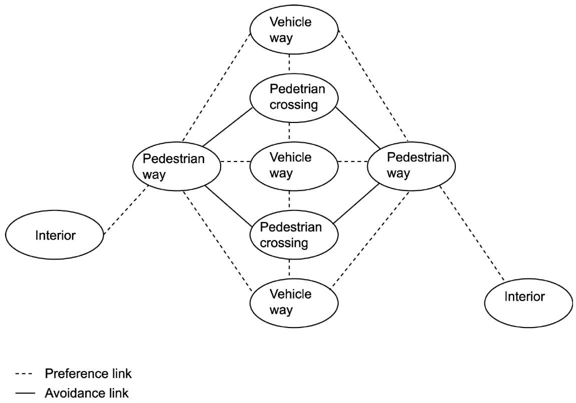


Figure 36. Example of an abstract topological graph queried by a pedestrian

6.15. 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.

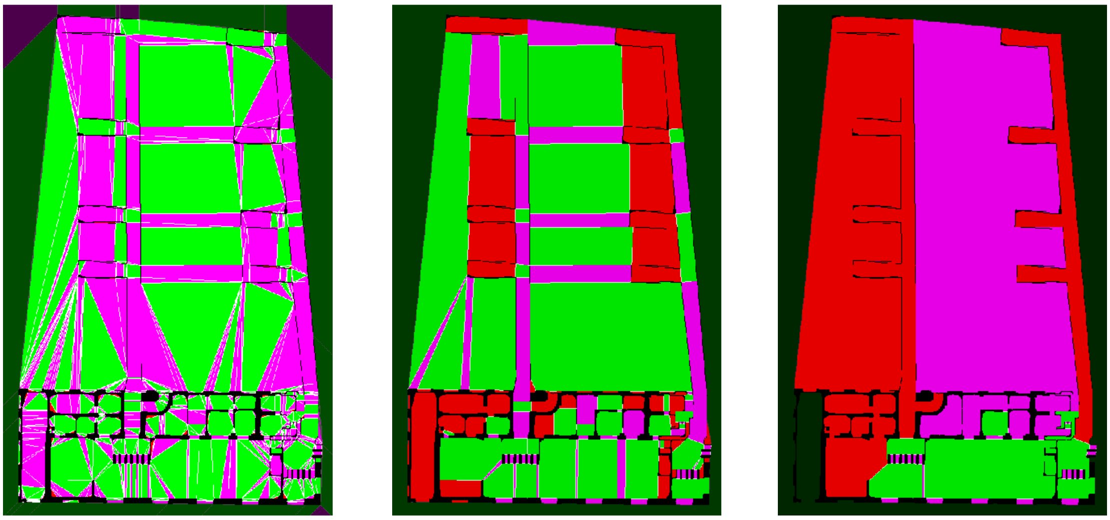
This study is carried out within the framework of an industrial thesis in collaboration with AREP, *Aménagement Recherche pour les Pôles d'Echange*, which is a subsidiary company of the SNCF, *Société Nationale de Chemins de Fer*. The goal of this study is to validate train station architectural plans with respect to the movements of people inside the station. The validation must take into account flows of people capacities of the environment, but also the way the entities can easily perform their tasks or locate themselves in the places.

6.15.1. Environment abstraction

The first point to be approached for the simulation of autonomous agents is the description of their navigation environment. Our model is based on F. Lamarche spatial subdivision, which produces a set of convex cells by using a constraint Delaunay triangulation. The first step, called *informed subdivision* (*Fig. 37*), computes a topological representation of the spatial subdivision by naming cells according to their number of connexity relations: *dead end* for one relation, *corridor* for two, and *crossroad* for three or more. Then, a two level hierarchical topological abstraction is performed (*Fig. 37*) to produce a more and more conceptual representation of the environment. This hierarchical graph is enhanced with some preprocessing, like potential visibility sets, and oriented grids linked to each *group* in order to evaluate local densities.

6.15.2. Path planning

The next necessary task to enable navigation inside an environment is path planning [32]. We propose to take advantage of the hierarchical topological abstraction to perform path planning by part. The path evaluation is first performed entirely on the more conceptual layer (*zones*), then it is refined on the visible nodes of the first abstraction layer, and finally on the informed subdivision layer to obtain the navigation path. The used crossing algorithm can be a *floodfill* if there are multiple destinations, or an A^* if there is only one possible destination. A multi-criteria heuristic is used in order to evaluate the navigation cost of the nodes, which only takes into



(a) Informed subdivision: 1526 cells (b) First abstraction: 153 groups (c) Second abstraction: 40 zones

Figure 37. Full abstraction of the St Denis trainstation

account the known part of the environment for the entity. This heuristic takes into account the travelling distance, the local densities of population and flows of people, the relative and absolute direction changes, and finally the width of the passages. Moreover, the heuristic parameters can be dynamically modified to reflect changes in the path planning behaviour of an entity. Finally, the path planning algorithm is reactive to events sent by the observation process, or by the rational procedure, which results on a partial of full path revaluation.

6.15.3. Navigation

The navigation procedure is the specific behaviour in charge of local collision prediction and avoidance of the simulated entities between each other. The most used model nowadays is the Helbing particle based one which has many problems:

1. It does not take into account any prediction level, waiting for the entities to collide before adapting their behaviour.
2. It produces oscillating adaptation directions which make it very difficult (not to say impossible) to connect to an animation module.
3. It manages so basic entities (particles) that it is hard to provide high level adaptations such as social behaviours.

To take ride out of these limitations we have recently worked on an alternative navigation model. Our model proposes a predictive detection toward static (like walls) as well as dynamic (like humanoids) entities. It allows to consider attractive as well as repulsive targets, making it possible to manage group formations and avoidance, and also to automatically find the best navigation and waiting areas for specific behaviours such as looking something or talking to someone. This model, in the contrary of the Helbing's one, is as well suited for high density environments as for low density ones. Moreover, the adaptation is very stable, allowing its computation at a very low frequency (1 or 2 times per second).

6.15.4. Interaction with objects and other actors

The interaction with objects and other actors is both hard to simulate and of great importance inside the kind of environment we are interested in, because of the great number of interactions entering in the behavioural procedures of the entities. The model we propose is close to the ecological theory of J.J. Gibson, describing interactions as *affordances* linked directly to the objects with which the interaction is possible. This model takes place as a platform called BIIO: *Behavioural Interactive and Introspective Objects* [55]. What we call *objects* are certainly physical objects like a chair or a door, but also agents representing virtual people. BIIO enables to attach *interactive behaviours* to objects, in a hierarchical way: each object inherit the properties of its parent(s), including interactions potentials (*Fig. 38*).

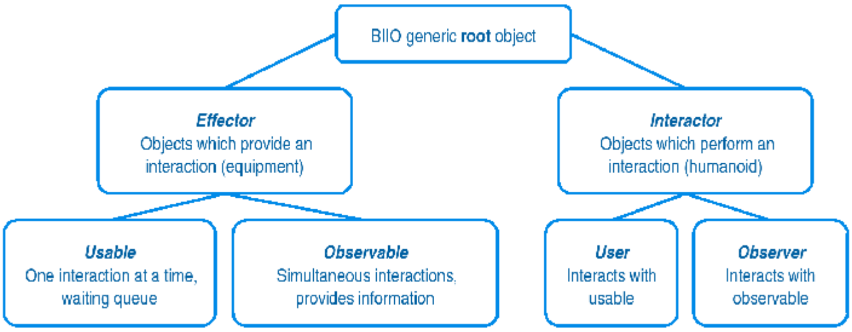


Figure 38. Base hierarchy of the BIIO objects

Moreover, the objects have strong introspection capacities which allow to take them into account for new behaviours without the need of any specific management, and also to read and change their properties in real time. The interactions are classified in two categories. First, using interactions are only available to one actor at the same time, which require to manage a waiting queue for the object. Second, observation interactions are available to many actors at the same time. An interaction is composed of four parts. A rational precondition, which is a boolean expression relative to the actor and the type of the object to interact with. A local precondition, which is a boolean expression relative to the actor and the object. An effect, which may affect one or both of the actor and the object. And finally, a duration which is relative to the actor and the object.

6.15.5. Results

We are currently implementing a simulation application, in the course of the RNTL project *SIMULEM*, which gathers all of these models (*Fig. 39*).

This application makes it easy to conduct simulations, and to observe what is going on thanks to BIIO. The environment is automatically extracted, subdivided, and abstracted from an AutoCAD source file. The interactive objects are also extracted from the AutoCAD file, which must follow some designing constraints. Finally, generators of humanoids are used to configure the flows of people inside the environment. The output of the simulation is a 3D animation, where people can be represented by static avatars or by animated ones thanks to MKM (*Fig. 40*).

6.16. Synoptic objects describing generic interaction processes to autonomous agents in an informed virtual environment

Participants: Marwan Badawi, Stéphane Donikian [contact].

6.16.1. Synoptic Objects

Synoptic Objects are objects designed to offer to the autonomous agent a summary, or synopsis, of what interactions they afford. When an agent queries such an object, it knows what actions it can perform, where

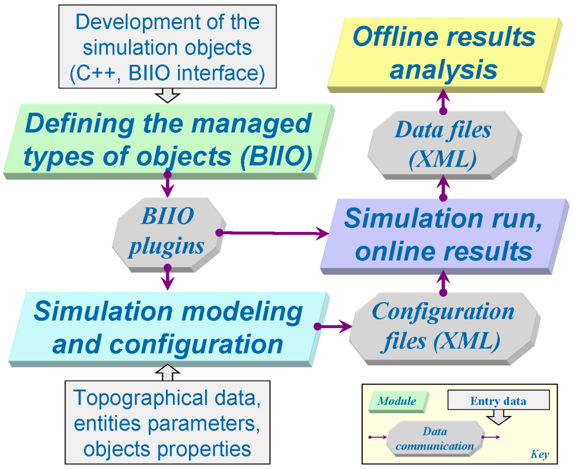
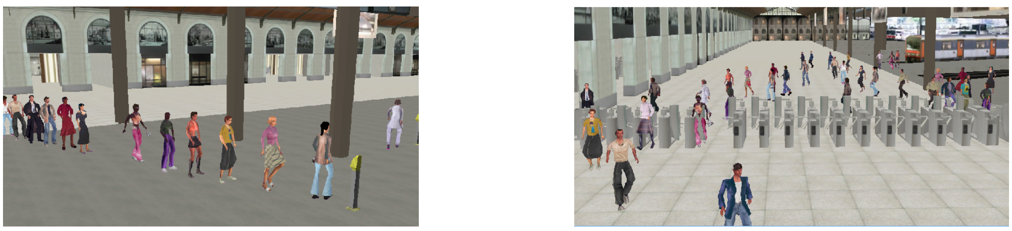


Figure 39. The simulation application architecture



(a) Waiting queue formation in front of a ticket puncher

(b) Automatic dispatching of the entities through turnstiles

Figure 40. 3D output of a simulation

it should position itself, where it should place its hands, what state the object is in, whether it is allowed to perform the action... All these indications, are given through the use of *Basic Actions* and *Interactive Surfaces*. An autonomous agent is itself considered as a synoptic object which allows interaction between agents (such as shaking hands) without any additional special considerations.

6.16.2. Interactive Surfaces

Interactive Surfaces are broken down into two types: *Interaction Surfaces* and *Influence Surfaces*. Interaction surfaces are parts of the object's geometry which indicate the hotspots on the objects surface which take part in the interaction. they can be used to indicate to the agent where to place its hand when it wants to grab an object, where to place its foot when walking up stairs, where to place its backside when sitting on a chair... Figure 41 illustrates the interactive surface used for grabbing a mug.

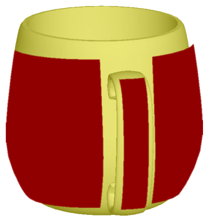


Figure 41. An interaction surface (in red) indicating hand placement for grabbing a mug.

Influence surfaces, on the other hand, describe the space around the object, affected by the interaction, such as where the agent should stand before it sits on a chair, the area it should avoid when it is opening a door... The term Interactive Surface (IS) will be used when talking about either of these two types of surfaces.

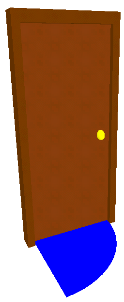


Figure 42. An influence surface (in blue) indicates the area to avoid while opening a door.

6.16.3. SHORe

SHORe is the **S**ynoptic and **H**umanoid **O**bject **Re**pository. It keeps track of all the ISs of all the objects within the simulation. Whenever an agent requests an interaction with an object, SHORe performs a collision prediction, based on the agent's and the object's ISs. This determines a contact point and normal on the corresponding ISs and allow the agent to recover specific geometric information which is best suited to it in order to perform the interaction.

6.16.4. Basic Actions

Basic Actions are associated to each of the ISs of an object. These actions tell the agent the action it needs to do while using the corresponding IS during interaction. In all, there are seven basic actions:

1. TRANSFER: This action is used to tell the agent to transfer itself to the object. It uses the IS to determine a target for the agent to walk to.
2. MOVE: This action is used to make the agent move a part of its body like reaching for an object, turning the head, lifting a leg... It uses MKM (see section 5.3) to either replay a motion captured movement, or modify it through spacetime constraints to adapt it to the interaction at hand.
3. GRASP: This action is used to make the object follow the agent when the body part that did the GRASP-ing is MOVE-ed. Furthermore, this action instructs the agent to use the GRASP-ed object's IS instead of its own when using the object. When an agent wishes to put a glass down on the table, it will use the IS on the bottom of the glass to determine where it should place its hand so that the glass's IS touches the table.
4. INGEST: This action is used by the agent to take something into its own body. It describes actions such as eating or drinking. It can also be used to create containers such as synoptic boxes or drawers that can INGEST other synoptic objects.
5. EXPEL: This action is the opposite of INGEST. A container can EXPEL any object it has previously INGEST-ed.
6. TELL: This action is used by the object to give the agent information specific to a sensor. It can target one of the five human senses, like sight or hearing, for example. It can also target other specific senses like a temperature sensor, for example.
7. ATTEND: This action is used by the agent to recover the information given by TELL. When the agent ATTEND-s a sensor to an object, it can recover the information being TELL-ed to that sensor.

The basic actions are generic and do not make any assumption on the nature of the agent. They only provide a description of the action to be performed, and it is up to the agent to interpret and execute the action in a way best suited to it.

6.16.5. Complex Actions

Complex Actions are a grouping of the basic actions associated to their specific ISs. They are in the form of HPTS++ finite state machines (see section 5.4). Complex actions describe a series of basic actions to perform in succession in order to accomplish a specific interaction process. They can describe things like *Open Door*, *Pick Up Object*, *Sit Down*...This allows multiple objects to share the same functionality. For example, all the synoptic doors will have the same description of *Open Door* complex action. But each door will have specific ISs for the complex action to use. This allows us to disassociate form from function: if a geometry of an object is changed, its functionality remains intact.

The *Open Door* complex action is illustrated in figure 43 where the agent can be seen pulling, pushing and sliding a door open, respectively from top to bottom. The decomposition of the *Open Door* complex action into its basic actions is as follows:

- TRANSFER the agent to the door.
- MOVE the arm towards the knob.
- GRASP the knob.
- MOVE the hand to turn the knob.
- MOVE the arm to open the door. TRANSFER the agent at the same time to follow the door.
- un-GRASP to let go of the knob.

Figure 43. The same Open Door complex action used with three types of doors.

Figure 44. An agent pouring water from a bottle into a glass.

Another example can be seen in figure 44. The top row of the figure shows a capture motion of an agent pouring water from a bottle into a glass. The bottom row uses ISs on the neck of the bottle and the rim of the glass to modify the motion and constrain the bottle's neck to the glass's rim.

This work resulted in the development of the STARFISH architecture which stands for **S**ynoptic-objects **T**racking **A**ctions **R**eceived **F**rom **I**nteractive **S**urfaces and **H**umanoids.

6.17. Scripted interactions in a virtual educational environment

Participants: Bruno Arnaldi, Nicolas Mollet.

We realized a part of a virtual formation environment. One can find the context of our project in the section "industrial contracts", and "GVT". Firstly, we realized a general pattern to obtain interactive objects and a generic interaction process: the STORM model. Secondly, we focused on the definition of what has to be done in this virtual environment, by using our interaction mechanism. That's the role of the language LORA. Finaly, our last contribution is an author-tool, based on STORM and LORA, which is able to generate scenarios by demonstration. Our objectives was to create generic designs, reusable objects and behaviors, and complex scenarios.

6.17.1. A general interaction model between behavioral objects

We wanted to obtain a generic treatment of interactions between behavioral objects. A classical problem of interaction between objects is the question *where should we put the definition of the interaction?* One solution is to put the definition of the interaction in the object itself. We can mention the works of Kallmann, with what he called "smart objects", or the work on Synoptic Objects developed by Badawi in our team. We thought that it would be interesting to have information about interaction in the objects, but not have the definition of interaction totally described in a particular object. This definition has to be located somewhere between the objects, with parts of definitions distributed between the objects concerned by the interaction. These parts are named "capacities". The definition of interaction located between the objects is named "relation". "Capacities" combination gives a set of interaction possibilities between objects doted with interaction capacities. The relation is finally responsible of the interaction process, by using the capacities of those objects. This work leads to the deposit of a patent. For example, let us consider only two objects, a screw and a nut. We want to create a screwing interaction between those objects. According to our model, the screw will have male-screwing capacity (length, thread pitch, the male state, etc.) and the nut will have female-screwing capacity (thread pitch, a boolean which indicates if there is already a screw on it, the female state, etc.). We will also have a "screwing relation" (cf figure 45). This relation contains the definitions of the screwing interaction: a male-screw can be screwed in a female-screw, when the size is good, when the thread pitches match, etc. This relation offers the possibility to screw the screw in the nut, and gives a certain state to this set of two objects: when it is screwed we can not manipulate the screw independently, and when we move the nut, it moves the screw. We can notice that the "screwing relation", the "female-screwing capacity" and the "male-screwing capacity" can be re-used whenever we need to define screwing interactions between two objects.

6.17.2. A graphical scenario language for complex interactions

Based on the preceding model of interactions, we wanted to have the ability to express a complex sequence of interactions. Thus our goal was to define the referential sequence of actions for a student in the formation environment. So we created a new scenario language named LORA. This language has two main aspects: it can be written directly, as we assume when we talk about a language. But it is also a graphical language. This language inherits from different graphical languages such as grafcets and statecharts, and also languages like HPTS for the hierarchical state machine aspect. Our language consists of steps, and links between steps. Each step describes an action which can be: an atomic action (in the previous example, we can select "screwing"), or a calculation action which uses internal variables, or a conditional action (the result of its evaluation has two possible ways when exiting) or a hierarchical action-step (a scenario can have steps which contain a sub-scenario. Those steps describe a global action locally). This language is interpreted and dynamic. Files are loaded and represented in memory in a virtual machine for scenarios. The memory of this machine can

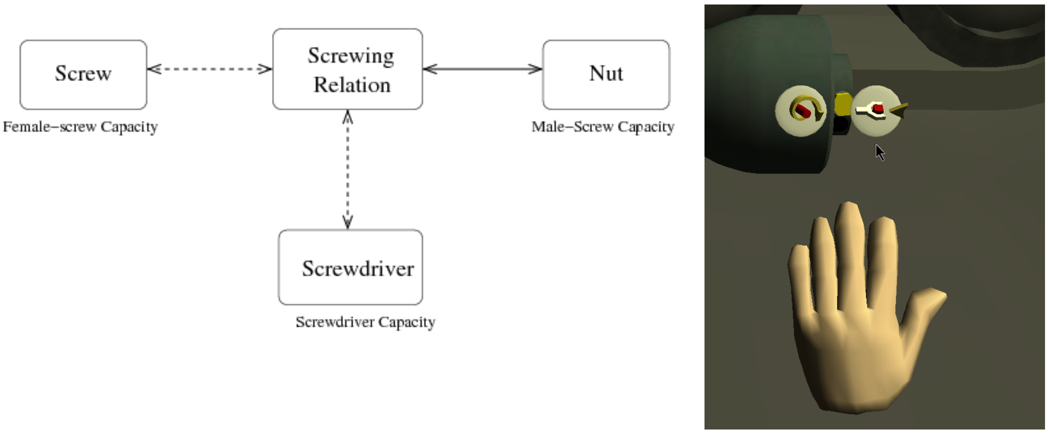


Figure 45. Example of application of the STORM model

be modified dynamically: the memory representation of the scenario is interpreted with the evolution of the scene. We can edit the language whenever we want in the virtual machine. After actions are executed in the environment, the virtual machine interprets next steps in its own memory. This work leads to the deposit of a patent, and to an international research paper[54].

6.17.3. An authoring-tool for scenarii

The creation of virtual training environment is a complex process, associated with high financial and temporal costs. The STORM and LORA models are totally generic, the main aim is the re-usability of objects and behaviors. As a consequence, the GVT project is turned to the design of a platform for the creation of such virtual environments. Our first tool in this platform is an authoring-tool for the creation of scenarii by demonstration. This tool is based on LORA and STORM. The author of scenarii is performing actions in the 3D-scene, in GVT. By the way, those interactions are represented with STORM, so we can directly create LORA's actions. With this tool, the author is now able to show the sequence of actions to do, and the scenarii is directly generated (cf figure 46). In the same time, the author can also work on the recorded sequence to adapt it with what he want: a parallel sequence, a hierarchical action, a conditional way, etc. This work leads to the deposit of a patent.

6.17.4. Actual work

>From a technical point of view, many work has been done in the development of GVT VR environment contents. >From a research point of view, we have initiate a communication process, with a first international research paper on GVT, and especially on the scenario language[54]. We are now working on evolutions of our models, to have more flexibility in the creation of GVT VR environments.

7. Contracts and Grants with Industry

7.1. Giat-Industrie: Virtual Training.

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

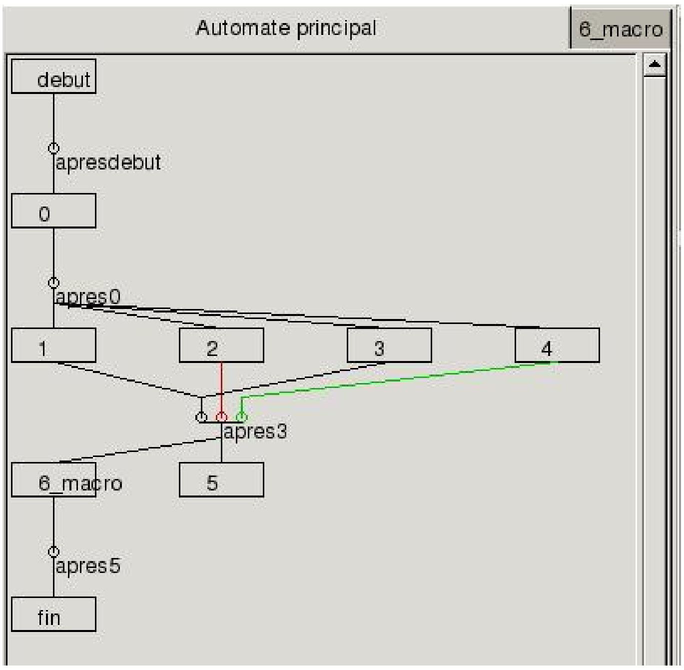


Figure 46. A generated scenario with the graphical aspect of LORA

The GVT-Giat Virtual Training project (INRIA, Giat-Industries and ENIB) is a very challenging one. Indeed, in this project, we introduce very advanced VR technology in order to produce very 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 with embedded behaviors: the STORM model.
- design of high level specification language, LORA, in order to describe complex 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.

For those three points, you can find more informations 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 still been shown at four meetings: Eurosatory, Perf-RV, Laval-Virtual and Intuition workshop. The GVT project leads to the depot of 5 french patents and 1 european patent. We can also cite a PhD and a research paper[54]. You can find more informations on the product in the "software" section.

7.2. ROBEA ECOVIA : Study of Visuo-Haptic Integration

Keywords: *Haptic*, *Perception*, *Robotics*, *Sensory Integration*, *Virtual Reality*, *Vision*.

Participants: Anatole Lécuyer, jean Sreng.

Figure 47. Immersed maintenance training - GVT

The aim of the ROBEA Project "ECOVIA" was to study human perception and integration of visual and haptic information. Our results intend to improve computer-human interaction in robotics during tele-operations or in virtual reality systems.

The ECOVIA project was planned to study human perception and visuo-haptic integration, and to identify the potential robotic applications. ECOVIA was planned for 2 years and has began on October 2003. It was a collaboration between 5 partners : 2 INRIA projects (i3D and Bunraku), CEA LIST (French Commission for Atomic Energy), Collège de France (LPPA), and University of Paris 5 (LCD).

This research was part of a complex project for the simulation and implementation of fulfilling Virtual Environments (VE) and for the application of sensory integration in a robotic context.

In this framework, it was of great interest to study the perception of integrated visual and haptic information. The comprehension and modelling of multimodal, and more specifically, visuo-haptic integration have been debated for ages. Ernst and Banks have recently proposed (Nature, 2002) a statistical model for the visuo-haptic integration based on the maximum-likelihood estimator (MLE) of the environmental property. They proposed a model in which each sensory channel contributes to the perception in an inversely proportional fashion to its variance (noise). Within ECOVIA, we first planned to test this model and second to study and if possible to model other aspects of visuo-haptic integration.

The research activity was divided into 5 research actions. Action 1 tested the correctness of the model proposed by Ernst and Banks in a different visuo-haptic environment. Action 2 focused on the influence of bimodal information (visual + haptic) on the elaboration and use of internal models. In the third action (Action 3), we studied the possibility for the modality weighting (as proposed by Ernst and Banks) to be related to other parameters than the noise of the signal. The fourth action (Action 4) proposed a physiological analysis of the visuo-haptic integration. Last, the fifth action (Action 5) provided the ECOVIA project with application perspectives. This action was first focused on the identification of potential applications of our fundamental results. Then we developed specific applications, in the field of robotics [53].

7.3. 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, Mingjun Zhong.

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 4 partners: IRISA/BUNRAKU (Virtual Reality), INSERM (Neurophysiology, real-time EEG), FRANCE TELECOM (signal processing, Human-Computer Interface), 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 available open-source software distributed over the internet (gforge INRIA). Three demonstrators will be built to illustrate the numerous possibilities of our technology, in the field of multimedia and assistance to disabled people.

7.4. Seule Avec Loup : Interactive Choreographic Navigation

Keywords: *Choreography*, *Interactive Navigation*, *Virtual Reality*.

Participants: Julien Bilavarn, Gildas Clenet, Stéphane Donikian [contact].

"Seule Avec Loup" invites the spectator into the dance of two 3D characters in an interactive choreographic world, made of enchanted forests or desert landscapes . The Wave Field Synthesis system (9 meter wall of spatialized sounds) and a 12x3 meters screen (wall of pictures) ensure the immersion of the spectator who entered this world (figure 48). All of its gestures are collected by a laser : the spectator becomes actor while moving, modifying in its own way the visual and sound environment. Created by the artists Nicole & Norbert Corsino, and developed in collaboration with us, IRCAM and Ars Numerica, this work was exposed in June 2006 at the Centre Georges Pompidou in Paris.

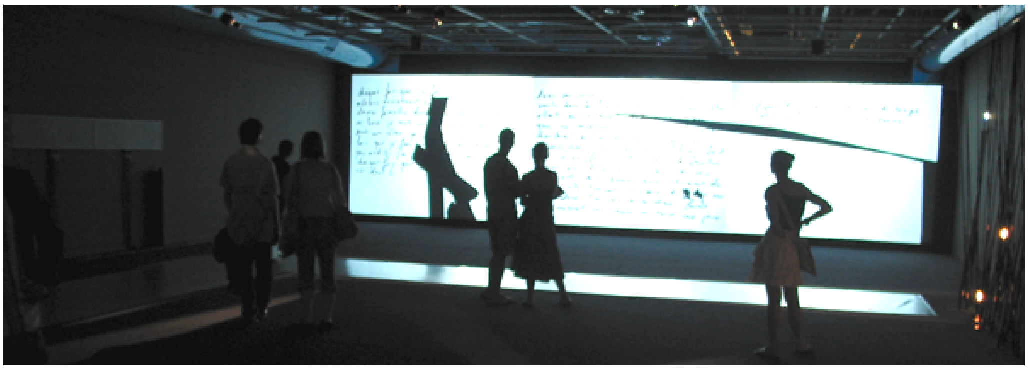


Figure 48. Overview of the exposition

Initially, the spectators should have two ways of interaction :

- by using a laser to determine several informations about the spectator displacements : its position, its speed, its direction ...
- by using the EyesWeb open source platform to capture the spectator gestures with a camera, and identify key postures.

After testing both of these systems, it appeared that the laser system was correctly functioning, but the EyesWeb system was not enough efficient because of the low-lighting conditions. Finally, only the laser system was kept to capture the spectator movements.

An OpenMASK application was then developped (figure 49) to be used as :

A Time Controller : OpenMASK manages the synchronisation between the visual rendering engine (Ogre 3D) and the sound rendering engine (Max MSP) ;

A Laser Interface : OpenMASK collects the laser dataflow and determine the spectator displacements (position, speed, direction, start/end of a displacement) ;

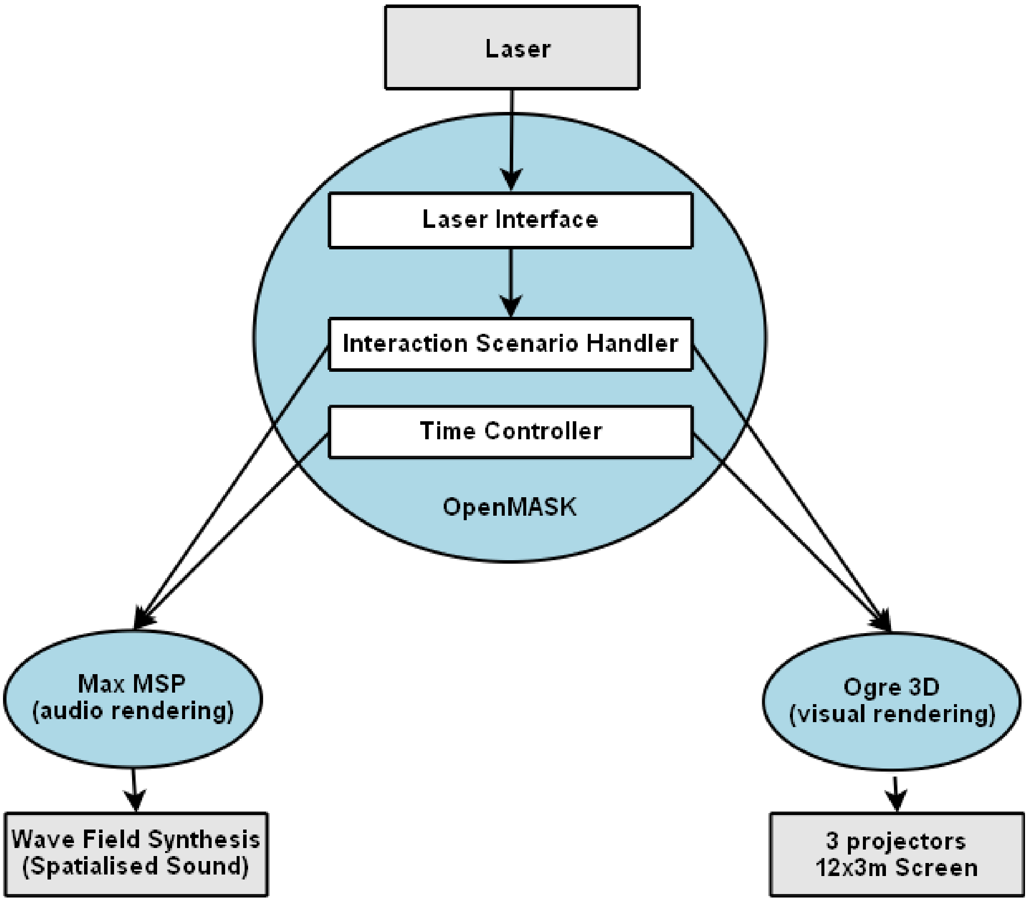


Figure 49. Overview of the OpenMASK application

An Interaction Scenario Handler : OpenMASK handles an Interaction Scenario, which describes at each moment the influence of a displacement on the visual and on the sound environment. If, at a given instant, a displacement is identified as influent, OpenMASK orders the visual rendering engine (Ogre 3D) and/or the sound rendering engine (Max MSP) to change the given parameters (characters size, speed of wind or water, camera movements ...). An important work of composition was necessary to script all these interactions and their influence on the visual world and the audio world.

7.5. 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 : participation to the 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, behavioural 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 : leading, specification of the human activity model, development of the human activity modeling language. Detailed specification of the informed environment model, development of an informed environment editor. Realization of a demonstration.

- 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 virtual human.

- Work package 4, scenario

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

  Our part : leading, specification and development of the scenario language.

7.6. CONCEPTMOVE

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

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

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. Within the same spectacle the theatre can mix with the dance and the circus, the live music with preregistered or computer generated soundtracks and reality with virtuality. A common point of a certain number of artistic works presented these last years is the use of 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, synthetizers and other multi-media peripherals. OSC is functionning 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.

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. We are now in the second work package which consists in the specification of the meta-language.

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 phenomena of crowd. The aim of the Simulem project is to develop a dedicated tool that allows simulating the individual and collective activity of autonomous agents in a public environment such as a railway station. Simulem involves two partners: AREP and us. AREP, subsidiary company of the French railway company SNCF, is an engineering and design department being interested mainly in the design and installation of the places of exchange such as the train stations. To apprehend these phenomena, to adapt to the traffic fluctuations and to prevent the disasters due to a bad appreciation of the conditions of safety of the people, it appears convenient to develop powerful tools. Currently available solutions are not specialized or dedicated to a field of activity, and apply as well to the modeling of office buildings, sporting equipment than airports. The project consists in designing the first tool for simulation dedicated to the train stations. The research objective of the project is to propose a multi-scale modeling allowing:

- to restore the logic of crowd which builds itself starting from the obstacle avoidance, the route planning and the individual goals of actors;
- to offer a realistic simulation of the personal interactions of the traveller with the objects of his environment generating by this way micro-behaviours;
- to restore logics of transport and exploitation at the train station level in its globality.

7.8. RNTL SALOME2

Keywords: *Simulation Platform*, *Virtual Reality*.

Participants: Georges Dumont, Jean-Marie Souffez, Bruno Arnaldi.

Salome2, RNTL project : The Bunraku project is involved in this RNTL project with twenty other partners (Open Cascade, Esi Software, Cedrat, Principia R&D, Mensi, Goset, Eads CCR, Renault, Bureau Veritas, CEA/Den, EDF R&D, CEA/List, Cstb, Brgm, Ifp, L3S, Inpg/Leg, Armines, Lan Paris6, Lma Pau). The SALOME 2 project aims to improve the distribution of digital simulation software developed in France which are considered references in their application domains. It provides them with a generic, user-friendly, and efficient user interface which facilitates cost reduction and reduces the delays in performing studies. It is a means of facilitating the linkage of code, the reuse of portions of code, the inter-operability between simulation code and the CAD modeling software. Our interest in this project is the coupling of the advanced Virtual Reality researches with the CAD environment. This project is now ended (since september 2006) and the PHD-Thesis of Jean-Marie Souffez has been defended this year [11].

8. Other Grants and Activities

8.1. National Actions

Figure 50. Example of a 5 different motions blending, carried out by MKM within Virtools software

"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 is to propose a national industrial software platform for simulating and optimizing a plant. We are working in the work package entitled "contribution to the virtual human" driven by

Dassault Systems. The goal is to propose techniques to animate and control virtual humans that have to work in the virtual plant. Those humans should be able to adapt their motion to the tasks that have been designed in a scenario proposed by industrial partners. The virtual human should be embedded in the Virtools software package. In this project, we are currently studying how MKM (cf paragraph 5.3) could be used to solve such a problem in Virtools. We have defined a set of significant scenarios with Dassault Systems and are currently developing demos with these scenarios, as illustrated figure 50.

8.2. Virtual Museum of Contemporary Photography

Participants: Alain Chauffaut, Stéphane Donikian [contact], Ahad Yari Rad.

Ahad Yari Rad, is a PhD student in Fine Arts, at the University of Rennes 2. His research subject concerns the Esthetic of Virtual Reality. He is performing the practical part of his PhD in the Bunraku's Project. He is currently developing a Virtual Museum of Contemporary Photography. This museum offers to the user the ability to navigate and interact with couples of photographs. By its own body movements and right arm gestures, the user has the ability to zoom in and out, to pan left and right and to step-by-step erase one photograph to make the second one appear (cf left picture of the figure 51).

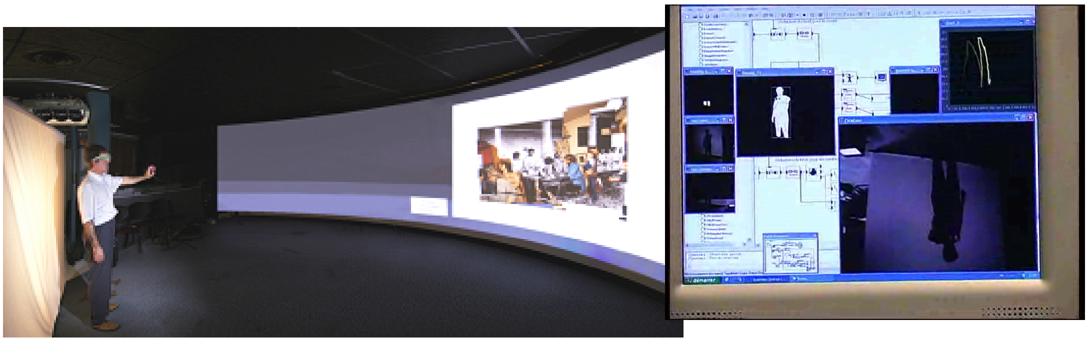


Figure 51. Contemporary photography Virtual Museum

This application combines together the use of EyesWeb for the user interaction (cf right picture of the figure 51), Max/MSP for the music composition and OpenMASK for the immersive environment management. The OSC (Open Sound Control) protocol is currently used for the communication between the different software, each of them running on a different computer. The necessity to build a higher level protocol over OSC, as it is so far just a transmission of integers or floating values, was one of our motivation to participate to the RIAM Project entitled ConceptMOVE.

8.3. 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.

8.3.1. 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:

- Improvement of Term of Reference (Sept-Oct 2005)
- Organization and participation in 3 WG Meetings: Stuttgart Sept 28th 2005, Laval April 25th 2006, Paris July 7th 2006
- Writing of 3 Documents Minutes of Meeting (Stuttgart, Laval, Paris)
- Organization and participation in 2 WG Leaders meeting : Brussels January 24th 2006, Rome May 2006
- Preparation of INTUITION EC Review (Nov 2005);
- Writing of WG2.10 Document Research Position Paper of Haptic WG (February 2006)
- Writing of WG2.10 Document Research Roadmap of Haptic WG (April 2006-August 2006)
- Building of haptic demos of Pseudo-haptic feedback for INTUITION website (February 2006-March 2006)
- Production of Poster, Papers, Demos, Booth for the 2nd INTUITION Workshop (Senlis, November 2005)
- Management, and production of Booth, Demos, Papers and Posters at EUROHAPTICS 2006 (Paris, July 2006)
- Organization of a Booth at LAVAL VIRTUAL 2006 (Laval, April 2006)
- Organization of a Special session on "Haptics in Industry" at LAVAL VIRTUAL 2006 (Laval, April 2006);
- Organization of a Tutorial on "Perception-based haptic rendering" at EUROHAPTICS 2006 (Paris, July 2006)
- Representative of INTUITION Haptic WG in Basel (October 2006)
- Roadmap document of the Haptic WG (October 2006)

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.

8.3.2. 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 ultimate goal is the design and realisation of a permanent organisation which will replace the NoE after the period of the EC financial support. The scope of this Organisation as perceived at the time being by the INTUITION members is to take on the Networks' successful ERA and proceed to and mostly overview a deep integration of the European competencies on VR. The major activity of this Work Package is the establishment and operation of the Network Business Office.

Key achievements:

- Work on the deliverable D1.F_2 “Network Business Office operational framework and business plan” (October 05)
- Design of the Business Office Leaflet (November 05)
- Preparation of the INRIA booth for INTUITION Workshop in Senlis (November 2005)
- Writing of the Milestone M15.1 “Network Business office” in the 2nd INTUITION Workshop (December 2005)
- Work in collaboration of ICCS in Greece during 1 month upon the Definition of the products and Services (March'06)
- Preparation, design and submission of the Web questionnaire (Two calls) (November 2005- February 2006)
- Preparation and participation at the NMC meeting and WG leader meeting in Brussels (February 2006)
- Breakdown and analysis of the Web questionnaire Results (April 2006)
- Preparation and submission of the Invitation to tender for the INTUITION Business Plan (April-May-June 2006)
- Definition of the Guideline for the evaluation process for the ITT (July 2006)
- Setting up and management of the Committee for the ITT evaluation (August 2006)
- Representative of INTUITION Business Office WP and NMC meeting in Basel (October 2006)
- Preparation, design and submission of the second Web questionnaire (October 2006)

The main Deliverable D1.F_2 report will include the description of the Operational framework of the BO, including a feasibility analysis of its potentials (from the legal to the commercial point of view). The BO is foreseen to be one of the funding mechanisms of the Network towards its sustainability. This deliverable must contain the analysis of the potential legal, commercial and financial structure of the BO. In case the BO proves not to be efficient other relevant mechanisms and tools will be initially proposed in this report. This report will also contain the business plan for the BO which has been undertaken by L-UP, after the relevant Call of Tender.

We have been the representative of INTUITION Haptic, Sustainability and Integration of Resource WG at the General Assembly in Basel (October 2006).

8.3.3. 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.

Figure 52. INRIA-Business Office booth

9. Dissemination

9.1. Scientific Community Animation

- Member of the core group of the RNTL Salome2 project, to develop relations between Computer Aided Design and Virtual Reality. G. Dumont. (end of the project in september)
- Member of the Francophone Association about Human-Machine Interaction (AFIHM): Thierry Duval.
- Thierry Duval is reviewer of the RIHM journal, of the IEEE VR 2007 Conference and of the IEEE 3DUI 2007 Conference.
- Nicolas Mollet is reviewer of IEEE VR 2007 Conference and of the CYBERWORLDS 2006 Conference.
- Nicolas 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).
- Reviewer for IEEE Trans. on Neur. Sys. & Rehab. Eng., Virtual Reality Journal, IEEE 3DUI (2006), ACM CHI (2006), ACM UIST (2006), Eurohaptics (2006), Cyberworlds (2006) (A. Lécuyer).
- Member of International Program Committee of Eurohaptics (2006), Cyberworlds (2006), NSI (2006) (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'06, CASA'06, AFRIGRAPH'05, GRAPP'06, EDUTAINMENT06.

- Chief Editor of the *Revue Electronique Francophone d'Informatique Graphique* (french computer graphics electronic journal): S. Donikian.
- 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'06, SIGGRAPH'06, 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.
- Member of "comité d'évaluation du RIAM": 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 : WSCG2006, Grafite2006, EG symposium on parallel graphics and visualization'2006 (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 in UK, Ireland, France (K. Bouatouch).
- Member of AFIG (French Association for Computer Graphics): F. Lamarche
- Reviewer of REFIG (French review of computer graphics) : F. Lamarche
- Reviewer of Eurographics 2006 : F. Lamarche
- Reviewer of SCA 2006 : F. Lamarche
- Member of the CCSTIC (National committee for STIC) : B. Arnaldi.
- Member of "Comité d'Orientation du RNTL": B. Arnaldi.

9.2. Courses in Universities

- MASTER MN-RV (Master of Numerical Models and Virtual Reality, University of Maine, Laval, France) : Physical models for virtual reality (G. Dumont).
- Mechanical Agregation course: mechanical science, plasticity, finite element method. ENS Cachan (G. Dumont).
- Teaching in numerical tools for mechanical simulation. ENS Cachan (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).
- MASTER MITIC (IFSIC), Modelling, Animation and Rendering (S. Donikian and F. Lamarche).
- Joint responsible for the MASTER OF COMPUTER SCIENCE (K. Bouatouch).

- 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: Ray Tracing and Volumic Visualization (K. Bouatouch).
- MASTER MITIC (IFSIC), Modelling, Animation and Rendering (S. Donikian and F. Lamarche).
- DIIC (IFSIC), Algorithmic and Programming (F. Lamarche).
- DIIC INC (IFSIC), Animation (F. Lamarche).
- DIIC INC (IFSIC), Image Synthesis (K. Bouatouch and F. Lamarche).
- LICENCE 2 (IFSIC), Reactive system conception (F. Lamarche).
- Computer Science MASTER OF COMPUTER SCIENCE Ifsic: Real-Time Motion (B. Arnaldi).

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