INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Bunraku

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

Rennes - Bretagne-Atlantique

THEME COG

Activity Report

2008

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2. Overall Objectives

2.1. Introduction

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

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

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

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

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

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

Our objectives are now decomposed into three complementary research themes:

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

2.2. Creation of the GOLÆM compagny

GOLÆM (http://www.golaem.com) is a french company, spinned off by BUNRAKU, that is expected to be created at the early beginning of 2009. GOLÆM was awarded in 2008 at the OSEO national enterprise creation competition (emergence category). GOLÆM will offer 3D business users an unprecedented range of software components, as well as complete solutions for simulations of individual and collective human behaviors in digital mock-ups. 8 members of Bunraku are involved in this creation supported by Emergys and INRIA Transfert.

2.3. FMX 2008 price

During the FMX 2008 conference, members of Bunraku and M2S research teams have been awarded a best *New Technology Price* for their work on TopoPlan, MKM and their combination. This price has been issued by a jury composed of industrials belonging to major companies in the domain (NVIDIA, Dreamworks, The Khronos Group, Inago).

3. Scientific Foundations

3.1. Panorama

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

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

3.2. Dynamic models of motion

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

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

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

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

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

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

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

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

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

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

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

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

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

3.3. 3D interaction

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

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

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

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

1. the interaction device, which sends the intentions of the user to the virtual environment (input device) and/or feeds back some information to him/her (output device);
2. the interaction technique, which corresponds to the interpretation of the information received or sent to the user by the system, i.e. the scenario of use of the interaction device when considering a specific task to be achieved in the virtual environment.

The design of 3D interaction techniques is conceived as an iterative process of *design-evaluation-redesign* which ends when the technique reaches its criteria of use. Another objective of the evaluation of the 3D interaction technique is to determine the model of performance, i.e. the prediction of the performance of the user given a certain task and a certain 3D interaction technique. The most famous example is probably the Fitts law (Equation 4) which predicts the time (T) spent to reach a target with a given width (W) and located at a given distance (D). In this equation, the constant a and b are determined empirically according to the pointing task and the interaction device used.

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

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

3.4. Visual Rendering

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

Global illumination : direct and indirect illumination computation.

Rendering: computation of an image of a virtual world as seen from a camera.

Partitioning : subdivision of a 3D model into cells.

Client-server : a server contains complex 3D scenes, a client sends requests for objects to the server.

GPU : Graphics Processing Unit.

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

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

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

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

3.5. Virtual Humans

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

Avatar: it is the representation of the user in the virtual world. This representation can be either anthropomorphic or metaphoric.

Autonomous Agent: An autonomous agent is a virtual human situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future.

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

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

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

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

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

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

4. Application Domains

4.1. Panorama

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

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

4.2. Industrial products and process

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

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

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

4.3. Narrative and Interactive Virtual Worlds

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

4.4. Quality of service inside public mobility areas

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

4.5. Sports and health care

Works dealing with human motion simulation are very interesting for sports scientists and for doctors in handicapped people rehabilitation. In sports simulation is an alternative to statistical analysis in order to identify the parameters lined to performance. Moreover simulation could also provide new training environments involving virtual reality. The problem here is to provide complementary tools to coaches in order to train specific capacities. In the continuity of the PhD thesis work of Benoit Bideau2 on the study of the duel between the real goal-keeper and the virtual fighter in an Hand-Ball game, we this year will extend this model by integrating follow-up of glance of the goal-keeper using an oculometer and a followup of the orientation of the head, but also will use the real-time functionalities of our new motion capture system in order to close again the loop and to allow the virtual fighter to adapt its behaviours to the reactions of the goal-keeper, which was not possible in the preceding version. In a future a little longer, we hope also to address tactical problems in the collective plays, to study and model them. This work is done jointly with the Biomechanics team of M2S (joint lab between the University of Rennes 2 and ENS Cachan).

4.6. Training

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

5. Software

5.1. Panorama

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

5.2. OpenMASK: Open-Source platform for Virtual Reality

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

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

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

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

During 2008, OpenMASK distribution feature has been re-implemented above MPI. Previously it was above PVM. We have also work to integrate Collada exchange format as OpenMASK application specification language.

With OpenMASK, we provide Model Driven Tools to help to build of OpenMASK applications. The main aim of this approach is to free the user of tedious and repeated coding and to improve reusability. Within Eclipse environment we offer an editor and a C++ code generator to design and build objects.

In 2008, we improved the original model, based on the OpenMASK version 3, to take into account the new features of the version 4. The new model includes the new items: extension and animators, it also uses the new data format. The version4 allows to use plug-ins, so we improved the new model tool to generate, not only the code of the object, but also the make files to build a fully functional OpenMASK plug-in, including the user documentation.

5.3. MKM: Manageable Kinematic Motions

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

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

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

This representation is based on a simplified skeleton which normalizes the global postural informations. This formalism is not linked to morphology and allows very fast motion retargetting and adaptation to geometric constraints that can change in real-time (cf figure 1). This approach dramatically reduces the post production and allows the animators to handle a general motion library instead of one library per avatar. 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.

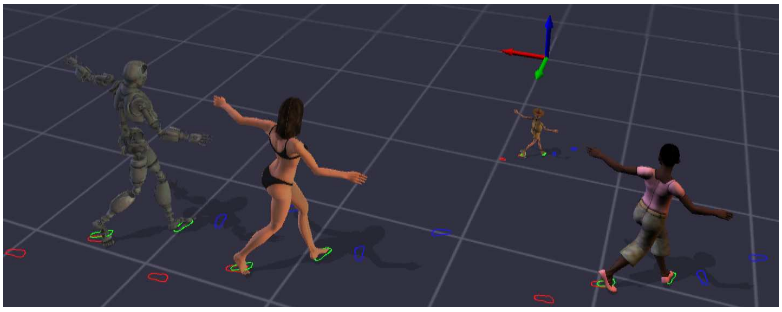

Figure 1. Morphology adaptative characters motions with MKM software

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

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

An inverse kinematic and kinetic solver was also developed, based on the morphological-independent representation of posture. Our inverse kinematics and kinetics module is based on an improvement of the Cyclic Coordinate Descent method. Moreover, we also introduced the control of the center of mass position in this algorithm.

This library has been used in several applications and it has been presented in SIGGRAPH 2008 exhibition at the Cap Digital's booth. It currently runs on Windows and Linux with different viewers and it has been also integrated in two different software architectures: OpenMASK (our own platform) and Virtools. This latter development is partially funded by the "Numerical Plant 2" project of the "system@tic" French competitiveness cluster (cf. paragraph 7.7).

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. Initially designed for behavioral animation, it provides a generic and platform independent framework to describe multi-agent systems. It is composed of a language and a runtime environment.

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. 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.

Recently, a task model has been added in HPTS++. This model provides a framework dedicated to the description of behaviors through tasks and operators described through HPTS++ state machines. Thanks to this model, the user can describe primitive behaviors through atomic tasks and combine them, thanks to the provided operators, to rapidly and easily create complex behaviors. Provided tasks operators are sequence (on success then, on failure then), parallelism, loops (while, for), alternative, all without order. Those operators are fully dynamic. Hence, they can be used at runtime to dynamically describe complex behaviors.

This toolkit runs under Windows and Linux systems. It has been used in different research fields such as behavioral animation, scenario description and automatic cinematography. Its scheduling system provides new paradigms for multi-agent systems description while ensuring the overall consistency of the execution.

5.5. GVT : Generic Virtual Training

Participants: Bruno Arnaldi, Xavier Larrodé, Stéphanie Gerbaud, Valérie Gouranton.

The aim of GVT software is to offer personalized VR training sessions for industrial equipments. The most important features are the human and equipment security in the VR training (in opposition to the real training), the optimization of the learning process, the creation of dedicated scenarios, multiple hardware configurations: laptop computer, immersion room (see figure 2), distribution on network, etc.

The actual kernel of GVT platform is divided into three elements that rely on innovative models proposed by IRISA (LORA and STORM models) and by CERV (for differentiated pedagogy). These models as well as the global platform have been presented in [37].

- A Behaviour Engine. The virtual world is composed of behavioural objects modelled with STORM (Simulation and Training Object-Relation Model).
- A Scenario Engine. This engine is used to determine the next steps of the procedure for a trainee, and its state evolves as the trainee achieves actions. The scenario is written in the LORA language (Language for Object-Relation Application).
- A Pedagogical Engine. This engine, employed to assist the trainer, uses the two engines above to decide what the trainee is allowed to do.

While a commercialized version of GVT proposes training on individual procedures, a new prototype is now available which enables users to train on collaborative procedures with virtual humans, as you can see on the right side of figure 2. See the "new results" section for more details about the models proposed in this prototype.

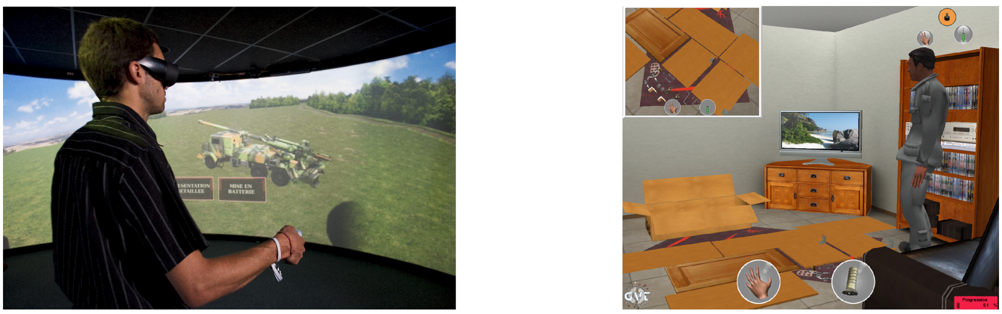

Figure 2. On the left - Immersed training. On the right - The collaborative prototype

5.6. TopoPlan: Topological Planner

Participants: Fabrice Lamarche [contact], Barthélémy Serres ,.

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

TopoPlan is based on an exact 3D spatial subdivision which accurately identify floor and ceiling constraints for each point of the environment. Thanks to this spatial subdivision and some humanoid characteristics, an environment topology is computed. This topology accurately identify navigable zones by connecting 3D cells of the spatial subdivision. Based on this topology several maps representing the environment are extracted. Those maps identify obstacle and step borders as well as bottlenecks. Based on this representation, several concise and accurate roadmaps are generated to handle real time path planning within the environment. This spatial representation is computed off-line thanks a tool provided by TopoPlan.

TopoPlan provides a library enabling the on-line exploitation of the spatial representation. This library provides several algorithms including roadmap-based path-planning, trajectory optimization, footprint generation, reactive navigation and spatial requests through custumizable spatial selectors.

Some algorithms such as trajectory optimization and footprint generation have been designed on a producer / consumer architecture to delay computational cost and be compatible with reactive navigation processes.

Provided algorithms and data structure do not relate to a virtual human animation toolkit. They are stand alone and can be easily connected to a user architecture.

This toolkit actually runs under Windows and compiles under Visual C++. It is actually used in several projects such as Perf-RV2 (see section 7.4) and Digital Plant 2 (see section 7.7)

5.7. TopoPlan Behavior

Participants: Fabrice Lamarche [contact], Barthélémy Serres ,.

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

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

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

TopoPlan behavior compiles runs under Windows and compiles under Visual C++. To be used, it needs TopoPlan, MKM and HPTS++. It is used in several projects such as Digital Plant 2 (see section 7.7) and Perf-RV2 (see section 7.4).

6. New Results

6.1. Muscle forces estimation from motion capture data

Keywords: *Motion Analysis*, *Muscle forces*, *Simulation*.

Participants: Charles Pontonnier, Georges Dumont.

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

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

1. acquisition of real motion data when following a prescribed scenario. This will lead to obtain a test database for motions that may occurs in a working situation;
2. proposition a kinematical model of the forearm with a special focus on the elbow. The real data will be mapped on this model to obtain the geometrical data related to the real human who have performed the prescribed task. This model is used to compute an inverse kinematics study to obtain the kinematical parameters related to this motion. These kinematical parameters are the angles at the joints during the motion phase;
3. inverse dynamics study of the forearm that leads to the joint torques related to the motion. This is achieved by building a dynamical model. The mass and inertia parameters used for this point are obtained by methods based on the literature;
4. use of these preliminary results as an input to a muscular model allowing to access to the forces that are developed inside the muscles. The current method proceeds with an optimization under non-linear constraints algorithm.

6.2. Haptic interaction with objects

Keywords: *Contact*, *Haptic Interaction*, *Impact*, *Multibody Dynamics*, *Simulation algorithms*.

Participants: Loïc Tching, Georges Dumont.

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

The contact/impact phenomenon is as discontinuous one leading to non smooth differential equation. Most of the proposed method to deal with haptic interaction in this case rely on penalty methods. These penalty method are used to regularize the mathematical formulation of the problem and allow to use classical numerical schemes. The major drawback is that it induces a "smoothness" in the haptic restitution and that the penalty coefficient is impossible to fix correctly without trial and error tests. As an alternative to these drawbacks, we adapt tools of computational mechanics for simulation of multibody systems, based on the NSCD framework.

In order to study the practical application of the non-smooth dynamics in haptic simulation, we developed a simulator that processes contacts, collisions and friction between objects in a virtual environment. This functional prototype is the implementation of the time-stepping approach of the non-smooth dynamics, which allows to simulate multi-objects environment in interaction between them. This prototype aims at the representation of realistic phenomena of the virtual objects, while being based on a faithful application of the mechanical phenomena. It allows to experiment the compatibility between the interface and the simulator, and between the collision detection algorithms and the contact treatment methods.

The first results on basic 3DOF virtual objects are greatly encouraging. We demonstrated that the NSCD method, originally fitted for granular environments, could provide pertinent results for haptic simulation.

Two different haptic interfaces (Haption Virtuose devices) have been coupled with our non-smooth dynamic simulator. This work is the subject of a Phd Thesis that began in 2007 granted by Haption SA, leader in design and production of haptic solutions (CIFRE contract). The work is integrated in the Part@ge ANR project (see section 7.5).

6.3. Subsurface scattering and eye modeling

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

Participants: Kadi Bouatouch, Guillaume François.

We have designed and implemented a software for real-time rendering of subsurface scattering within translucent materials. Subsurface scattering within translucent objects is a complex phenomenon. Designing and rendering this kind of material requires a faithful description of their aspects as well as a realistic simulation of their interaction with light. Our contribution is a new method for modeling and rendering complex organic materials made up of multiple layers of variable thickness. The material modeling is based on simple texture mapping principle, called Subsurface Texture Mapping. Our rendering method calculates the single scattering contribution for this kind of material in real-time using commodity graphic hardware.

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

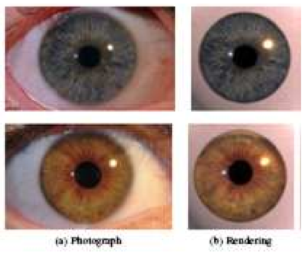

Figure 3. cloning the eye

We have proposed a novel method that allows to recover the iris structure and scattering features from a single eye photograph. In this aim, we developed a method to unrefract iris photographs. We modeled the iris using the Subsurface Texture Mapping representation which allows to describe the relieves of the human iris. Finally, we introduced a refraction function for accurate real-time rendering of the eye, accounting for the refraction of the light at the corneal interface (cf figure 3).

6.4. Real-time Rendering for Multiview Autostereoscopic Displays

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

Participants: Kadi Bouatouch, Rémi Cozot, Christian Bouville.

Multiview autostereoscopic displays are now available at affordable cost and are set to become widely used in virtual reality applications and 3D games. With their wide viewing zone, this type of display easily accommodates multiple viewers and no head tracking is required. However, real time rendering on these displays poses a number of difficult problems, the first one being of course the simultaneous generation of several views of the same 3D scene. Besides, the particular sampling pattern of the displayed image requires specific anti-aliasing procedures and this results in limiting the usable depth range. The purpose of our work is thus to tackle these problems. In particular, we have tested various virtual cameras settings with a view to keep the region of interest within the usable depth range of the display. We have also developed rendering methods allowing the generation of the interlaced multiview image with a commodity graphic hardware. Our method accounts for the depth of field effect in case of multiview autostereoscopic display.

6.5. Interactive Global Illumination

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

Participants: Kadi Bouatouch, Jonathan Brouillat.

We have extended the irradiance caching approach to indirect glossy global illumination. Our algorithm relies on radiance caching. It is based on the caching of directional incoming radiances. We have also developed the radiance cache splatting algorithm which allows to compute global illumination using programmable graphics hardware. Using a reformulation of irradiance and radiance caching, our method relies on the capabilities of GPUs to perform radiance interpolation.

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.

We have proposed a method which exploits the advantages of photon mapping and irradiance caching. We wanted to avoid the computationally expensive pass of final gathering needed by the photon mapping approach. Our algorithm computes an irradiance cache directly from the information contained in the photon map. The cache accounts for multiple-bounce reflections. Unlike irradiance caching, it covers most parts of the scene without any user intervention. The computed cache can then be used with radiance cache splatting for real time rendering.

6.6. Rendering globally illuminated natural scenes

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

Participants: Kadi Bouatouch, Kévin Boulanger.

Nature scenes from real life contain a huge number of small details which are hard to model, take a lot of time to render and require a huge amount of memory, unavailable in current computers. This complexity mainly comes from geometry and lighting. The geometric complexity is due to a high number of grass blades or tree leaves for example, and a huge number of primitives such as triangles are needed to accurately model them; lighting computation complexity is due to the multiple reflections of light over the scene objects with complex materials. Overcoming this complexity has been a challenging problem for many years. We address this problem in the context of grass and tree rendering. Our goal is to achieve real-time rendering of nature scenes while providing visually convincing dynamic global illumination. Our approach aims at rendering large amounts of natural elements, such as grass and trees, with approximations that reduce the rendering time while giving the convincing illusion of global illumination in dynamic scenes.

Figure 4. Trees

Our method allows the rendering of a soccer field, containing approximately half a billion grass blades, with dynamic lighting in real-time. It is also capable of rendering complex trees with global illumination computation (as illustrated by figure 4).

6.7. Color human perception rendering

Participants: Kadi Bouatouch, Christian Bouville, Rémi Cozot.

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

The chromatic adaptation also called white balance is one of these CAM key features. Even state of the art chromatic adaptation algorithms do not give good results in the case of global illumination because they makes strong assumptions about the 'real' image to white balance. Unfortunately theses assumptions are no more true in 'virtual' images.

So we purpose a new chromatic adaption algorithm suitable with global illumination. This algorithm takes direct and indirect illuminations (i.e. diffuse inter-reflection) into acount. Our algorithm does not depend of the global illumination engine, it works with radiosity, stochastic ray tracing and photon mapping engines.

6.8. Bayesian Monte Carlo for rendering

Keywords: *Global illumination*, *bayesian*, *monte carlo*.

Participants: Kadi Bouatouch [contact], Jonathan Brouillat.

Global illumination techniques based on raytracing make intensive use of Monte Carlo techniques. The luminance incoming to the eye through a pixel is computed by performing Monte Carlo integration over a multi-dimensional complex function. Several methods have been proposed to reduce the variance of the result of Monte Carlo integration : stratification, importance sampling and control variates.

Bayesian Monte Carlo techniques are widely used in the domain of Machine Learning, and relies on priors over the function of interest to improve Monte Carlo computations. We propose to use Bayesian Monte Carlo integration to compute global illumination, and improve the quality of final gathering. For a similar quality of rendering, Bayesian Monte Carlo allows us to cast less rays, hence reducing the rendering time. Choosing a prior for the incoming luminance function need to be done carefully in order to effectively reduce variance. In addition, Bayesian Monte Carlo integration requires inversion of large matrices, which can negate the advantages of casting less rays. We propose an adequate precomputing scheme which do not introduce bias in the estimation.

By using an adequate probability distribution function, one can reduce the variance of the Monte Carlo estimator (importance sampling). On the opposite, Bayesian Monte Carlo make no assumption over the distribution of the samples. However, by minimizing the theoretical expression of the variance of the estimator, we find an optimal distribution of samples, which can be jittered to perform a more accurate Bayesian Monte Carlo integration.

6.9. Interactions within 3D Virtual Universes

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

Participants: Thierry Duval [contact], Laurent Aguerreche, Benoît Chanclou, Alain Chauffaut, Cédric Fleury.

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

6.9.1. Generic Interaction Tools for Collaboration

Our goal is to propose software utilities in order to help implementation of new interaction metaphors for collaborative virtual environments. These software utilities rely on a generic interaction protocol that describes what kind of data an interaction tool needs to exchange with an interactive object in order to take control of it, and ought to be generic enough in order to be deployed on different software integration platforms such as OpenMASK, Spin3D or Virtools.

This year we have made a state of the art about 3D interactions (paradigms and metaphors) in order to propose an interaction protocol able to fit with the most commonly used 3D interactions. The first description of this interaction protocol that had been proposed in the context of the Part@ge project (deliverable 1.4.1) has been revised, we have implemented it with OpenMASK, and Clarté (one of our Part@ge partners) has implemented it with the Virtools VR Pack. Several versions of this protocol have been described in [62] and [60].Another result of this work is the definition of the interactive properties of interactive objects and interaction tools. In relation with some partners of the Part@ge project, we propose an extension to Collada in order to describe an interactive universe.

6.9.2. The Immersive Virtual Cabin (IVC)

The objective of the Immersive Virtual Cabin is to improve the user's immersion with all his real tools and so to make the design and the use of 3D interaction techniques easier, and to make possible to use them in various contexts, either for different kinds of applications, or with different kinds of physical input devices. This tool is dedicated to interaction and navigation within Multi-Scale Collaborative Virtual Environments (MSCVE). We have now a fully usable IVC which is a set of reusable modules within the OpenMASK Collaborative VR development framework. 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. 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 concept of IVC has been presented at the annual AFRV conference [61].

6.9.3. Interaction and navigation tools for exploration of scientific data

We also study how our IVC and our generic interaction tools and protocol could be used in the context of exploitation of 3D visualisation of scientific data (results of scientific calculations upon physical data), in order to make it easy to navigate within virtual universes showing such results and to enable several user to share common interactions with these scientific datas. This is a collaboration with EDF in the context of another ANR Project: the SCOS Project. Figure 5 shows the kind of scientific datas that EDF provides and that we have to explore in this context. A demonstration of this work has been presented at the Laval Virtual and Nem Summit manifestations, and at the VRST'2008 conference [34].

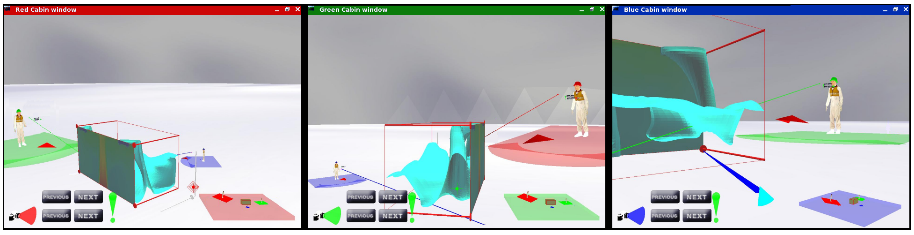

Figure 5. Three views of the exploration of results of scientific calculations with the IVC

6.10. Haptic Interaction

Keywords: *Contact*, *Event-Based*, *Haptic interaction*, *Nanoscale*, *Pseudo-Haptic*, *Teleoperation*, *Vibration*.

Participants: Anatole Lécuyer [contact], Bruno Arnaldi, Jean Sreng, Zhan Gao.

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 with virtual environments concerning : (1) pseudo-haptic feedback, (2) haptic interaction at nanoscopic scale, and (3) the use of vibrations to enhance contact simulation.

6.10.1. Pseudo-Haptic Feedback

We have first conducted a survey of main research and application concerning "pseudo-haptic feedback", i.e., a technique meant to simulate haptic sensations without using haptic interfaces, but using visual feedback and passive input devices. This survey will be soon published in Presence journal [18].

Then, we have proposed to extend the concept of pseudo-haptic textures, i.e., the possibility to simulate sensations of texture by using the sole manipulation of the speed of a mouse cursor (hereby called Speed technique). We have developed another technique to enhance the Speed technique and simulate texture sensations by varying the size of the cursor according to the local height of the texture displayed on the computer screen. Taken together, our results promote the use of both techniques for the low-cost simulation of texture sensations in applications such as videogames, internet, graphical user interfaces, etc. This work was published in ACM Transactions on Applied Perception journal [17].

Last, we have studied the application of pseudo-haptic textures in a medical simulator called SAILOR, for the training of loco-regional anaesthesia (LRA) with neurostimulation. The pseudo-haptic effects enhance the palpation of the virtual patient's body, in order to feel the inner organs. The first feedback from users of the commercialized DVD version of SAILOR as well as the results of pilot tests suggest that this simulator is a very promising tool for education and training for LRA procedures. This work was published in ACM Symposium on Virtual Reality Software and Technology [24].

6.10.2. Haptic interaction at nanoscopic and microscopic scales

We have developped an experimental platform for studying haptic interaction at nanoscopic and microscopic scales. It is based on haptic and virtual reality technologies and enables its users to interact in real-time with nano-objects, such as carbon nano-tubes. This simulator was developed for the purpose of investigating education, training and prototyping of telemanipulation of nano-objects. This work was published in ACM Symposium on Virtual Reality Software and Technology [35].

Then, we have conducted a study on the learning and understanding of nanoscale phenomena, for people without prior knowledge of nanophysics. This study was focused on the learning of a foremost one-dimensional nanophysical phenomenon: the approach-retract cycle of an Atomic Force Microcope (AFM) probe, with force-feedback and two different graphic representations. One representation is a virtual AFM cantilever and the other one is a virtual magnet-spring system, whose haptic behavior is analog. Preliminary results from an experiment conducted with 45 students suggest a better efficiency of learning with the combination of both haptic feedback and visual analogy. This work was published in Eurohaptics conference [46]. It was a collaboration with LRP and University of Paris 5.

6.10.3. Event-based rendering of contact using vibration patterns

An impact on a manipulated object creates high-frequency propagating vibrations. These vibrations produce different transient patterns sensed by the hand depending on the impact position on the object. Thus, we have investigated the ability to perceive the impact location through the haptic perception of vibration patterns using models based on a vibrating cantilever beam (See Figure 6). A perceptive evaluation has been conducted using six different vibration models. The global results showed that the users were able to associate vibration information with impact position. Taken together, our results suggest that the vibration models based on frequency changes could be a good compromise between realism and performance. This work was published in the Eurohaptics conference [55]. It was a collaboration with CEA LIST.

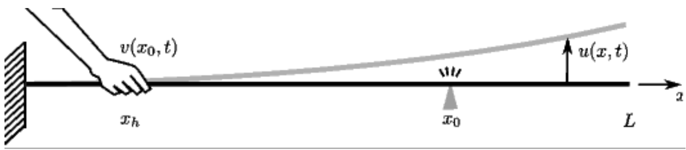

Figure 6. Event-based generation of vibrations using a vibrating beam model

6.11. Brain-Computer Interaction in Virtual Reality

Keywords: *BCI*, *Brain-Computer Interface*, *Classification*, *ElectroEncephaloGraphy*.

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

Brain-computer interfaces (BCI) are communication systems which enable to send commands to a computer using only the brain activity (which is generally sensed with electroencephalography, i.e., EEG). We describe hereafter our recent results in the field of brain-computer interaction with virtual environments: (1) Signal Processing and Classification Techniques for EEG-based Brain-Computer Interfaces, and (2) Brain-Computer Interactions with Virtual Worlds.

6.11.1. Signal Processing and Classification Techniques for EEG-based Brain-Computer Interfaces

A first part of the BCI research conducted in the team is dedicated to EEG signal processing and classification techniques. In a first study, we have introduced classification algorithms for BCI based on Gaussian processes. Our study has evaluated these algorithms and has compared them with commonly used techniques, on motor imagery data. Our results showed that Gaussian processes could reach better results than current methods. This study has been published in the Pattern Recognition Letters journal [21].

In a second study, we proposed to consider the design of self-paced BCI as a pattern rejection problem. In this regard, we introduced new rejection techniques for BCI, and compared them while using different kinds of classifier, on motor imagery data. Our results showed that non-linear classifiers associated with the reject class method lead to the most efficient self-paced BCI. These results have been published in the International Conference on Pattern Recognition (ICPR) [44].

6.11.2. Brain-Computer Interaction with Virtual Worlds

A second part of our BCI research is dedicated to BCI interaction with VR applications. To this end, we have studied the preferences and performances of 21 naive subjects who used a self-paced BCI to interact with an entertaining VR application (see Figure 7). Our results stressed the need to use subject-specific BCI as well as the importance of the real-time visual feedback. This work has been published in the International Brain-Computer Interface Workshop and Training Course [45].

Besides, we have conducted a survey of existing and future applications of virtual reality and video games based on BCI. This study was performed jointly with leaders in the field from other laboratories and was published in the IEEE Computer journal [16].

Figure 7. "Use the force application": Brain-computer interaction with an entertaining virtual world (©Hubert Raguet/Photothèque CNRS).

6.12. Interactive visual rendering

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

Most virtual reality applications need real-time visual rendering. However, the virtual images may sometimes look "too synthetic" or "too perfect" and, therefore, might provide a weak immersion feeling. Thus, we have studied innovative techniques to adapt the visual rendering interactively to the user's gaze, in order to enhance the final graphic rendering and the immersion feeling. Hereafter, we describe our recent results obtained in the field of "interactive visual rendering": (1) a novel Depth-of-Field visual blur effect, and (2) the use of eye-tracking to improve visual rendering.

6.12.1. Depth-of-Field visual blur effect

Depth-of-field (DoF) of the human's eyes is the range of distances near the point of focus where the eyes perceive the image as sharp. Objects behind and in front of the point of focus are blurred. Depth-of-field and its associated blur effects are well-known and classical depth cues in human vision, and they have been already introduced in computer graphics years ago. We have studied several techniques to improve real-time Depth-of-Field blur rendering (see Figure 8): a novel blur computation based on the GPU, an auto-focus zone to automatically compute the user's focal distance without an eye-tracking system, and a temporal filtering that simulates the accommodation phenomenon. Then, using an eye-tracking system, we have analyzed users' focus point during first-person navigation in order to better set the parameters of our algorithm. Lastly, we have conducted an experiment to study the influence of visual blur effects on performance and subjective preference of first-person shooter gamers. Our results suggest that our blur effects could improve fun or realism of rendering, making them suitable for video gamers, depending however on their level of expertise. This work was published in IEEE Computer Graphics and Applications [15].

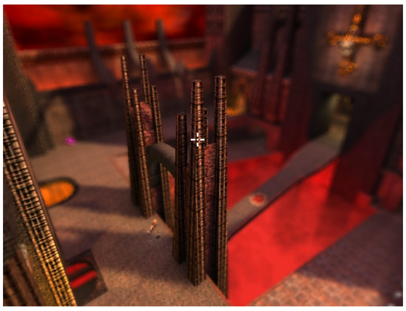

Figure 8. Virtual environment with real-time blur effects

6.12.2. Using an eye-tracking system to improve visual rendering and camera motions

We have studied the use of user's focus point to improve visual rendering in virtual environments. First, we have studied how to retrieve user's focus point in the 3D virtual environments using an eye-tracking system. Then, we have proposed the adaptation of two rendering techniques: (1) a camera motion which simulates eyes movement when walking, and (2) Depth-of-Field (DoF) blur effect. Second, we have conducted an experiment to study users' subjective preferences concerning these visual effects during first-person navigation in VE. It showed that participants globally preferred the use of these effects when they are dynamically adapted to the focus point in the VE. Taken together, our results suggest that the use of visual effects exploiting users' focus point could be used in several VR applications involving first-person navigation such as the visit of architectural site, training simulations, video games, etc. This work was published in IEEE International Conference on Virtual Reality [40].

6.13. Virtual reality to analyze interaction between humans

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

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

Understanding interaction between humans is very challenging because it addresses many complex phenomena including perception, decision-making, cognition, social behaviors...Consequently, defining a protocol for studying a subset of those phenomena is really complex for real situations. Using VR to standardize experimental situations is a very promising issue: experimenters can accurately control the simulated environment, contrary to real world. However, the main problem is: how to ensure that people behave as in real world when they are immersed in a simulated environment?

In the past, in collaboration with M2S (University Rennes2), we have worked on the interaction between two opponents in handball. We have designed a framework to animate virtual throwers in a reality center and to analyze the gestures of real goalkeepers that objective was to intercept the corresponding virtual balls. The main advantage of this situation is that the goalkeeper has to anticipate the trajectory of the ball according to the opponent's gestures otherwise it could not have enough time to intercept the ball.

These works are currently extended to other sports such as rugby and tennis. Indeed, each sport has some specific features such as the time for the athlete to take some information on the ball trajectory in the case of the tennis for example. In the context of a duel in rugby, on the contrary, all the information have to be extracted from the motion of the opponent in order to determine his intentions. Concurrently, we are working on the comparison between the use of video and virtual reality for sports analysis.

This work will continue to involve specialists in sports sciences (M2S of University Rennes 2) and neuroscientists (Queen's University of Belfast and UMR 6152 "Mouvement et Perception" in Marseille).

6.14. Virtual reality to analyze interaction between humans

Keywords: *Motion retieval*, *interactions between real and virtual humans*, *interactive virtual human*, *motion adaptation*.

Participants: Franck Multon [contact], Richard Kulpa, Nicolas Pronost.

One of the main issues in designing interactive virtual humans is the motion controller which has to select an appropriate motion according to the actions of the users. In real-time, the system has to identify which motion is required to collaborate with the user in a natural manner. Once such an action is identified, the controller has to tune the corresponding motion in order to accurately satisfy the constraints imposed by the user and the 3D environment. Contrary to many classical approaches based on spacetime optimization or motion graphs, the system is able to react to actions performed by the user in real-time. Hence, it's impossible to calculate a motion which satisfies all the constraints as it's impossible to predict them.

Moreover the constraints should be adapted to the morphology of the actor that performed each candidate motion. Other approaches generally assume that the database is made with only one actor with dimensions corresponding to the virtual character. Hence, retrieving the most convenient motion for another skeleton leads to preprocessing all the database: all the motions are retargetted to the desired skeleton. As our search algorithm directly deals with this difference of morphology, the method developed in this section doesn't require this preprocessing. As a result, the algorithm is able to return a different motion if the character is tall or small. Because the size of the database is not infinite, even the best candidate may not satisfy precisely all the constraints imposed on the character. As a second step of the algorithm, the selected motion is then adapted locally in order to accurately satisfy these constraints. This adaptation process allows dealing with a large set of possible movements even if no candidate of the database exactly fit the constraints.

This work has been carried-out in collaboration with the State Key Lab CAD& CG (Zheijiang Univ. in China) whose researchers are experts in retrieving motions into a database according to a set of high-level constraints.

6.15. Dynamics in humanoid motions

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

Participants: Franck Multon, Richard Kulpa, Ludovic Hoyet.

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

In the past, we proposed a method that was able to adjust the pose of a character during the aerial phase if the angular and linear momentums don't satisfy the physical laws. The method was based on adjusting the pose of the character by applying two different strategies: rotating the whole body to change the overall angular velocity or moving only parts of the body (such as the arms) to compensate an error in the global angular momentum. This method is able to animate up to 15 characters at 30Hz on a common computer. However, it's limited to aerial phase where no force except the body weight exist.

The dynamic corrections consist in adapting the joint angles if the corresponding whole-body motion doesn't satisfy the mechanical laws. During contact phases, if the user adds external forces that were not initially considered, the system should be able to adapt the sequence of poses to react to this perturbation. For example, when a character is pushing a cupboard, he should adapt his poses in order to react to the corresponding external force. The same way, when a character is turning, he should react to centrifugal accelerations by bending the whole body inside the turn.

Left part of figure 9 depicts a character that has to push a furniture. Depending on the weight of the furniture and the friction forces on the ground, the virtual human has to compensate an external force applied to his hands. In this figure, the lightgreen character stands for the original pose, without external force.

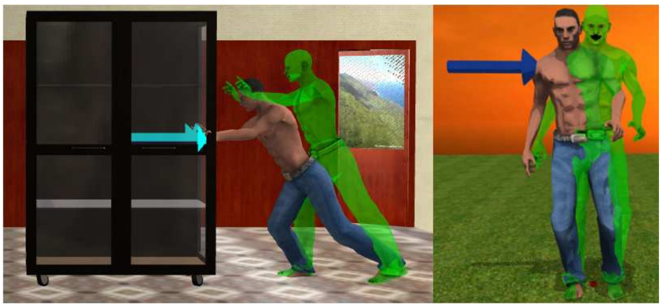

Figure 9. Physically-valid interactions with external forces.

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

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

Participant: Fabrice Lamarche [contact].

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

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

(a) (b)

Figure 10. Real time motion adaptation computed thanks to TopoPlan

bottlenecks on flat or uneven surfaces. Finally, thanks to the 3D subdivision, ceiling is also identified. Once the subdivision and its topology are extracted, they can be used in real-time to compute paths inside 3D complex environments.

As illustrated in figure 10, a virtual character animated by MKM can plan a path inside a complex environment and adapt its motion to the ceiling geometry and the floor constraints (spiral staircase and beam avoidance in Figure 10 (a) and ceiling constraints in 10 (b)).

6.17. Locomotion model

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

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

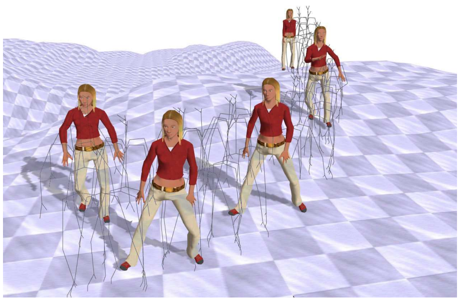

Figure 11. Example of a generated animation

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

An example of generated movement is presented fig. 11. This example shows a virtual human following a curve trajectory while facing the camera. Automatically, the locomotion model chooses the most adapted animations corresponding to the navigation parameters by smoothly combining forward, lateral and backward motions in accordance with the dynamically changing parameters generated by the reactive navigation model.

6.18. Virtual Humans' Navigation

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

Navigation is a crucial activity for Virtual Humans. Numerous questions need addressing when simulating such a behavior, which depends on the various possible contexts and simulation objectives. We focused on three different problems: the realistic simulation of interactions between walking virtual humans, populating large virtual environments with numerous virtual pedestrians, and immersing a real user among virtual pedestrians.

An interaction between two pedestrians occur when their nominal locomotor trajectories need adaptation in order to avoid a collision between them. We propose a model for solving interactions between walking virtual humans with a high level of realism. In order to elaborate our model, we first studied real interactions between real humans using motion capture: we acquired numerous experimental data according to specific protocols that allowed us to identify and understand major factors in such a phenomenon. The proposed model takes into account all of these factors. We then calibrated the model parameters from experimental data using maximum likelihood techniques: we can then guarantee the model to reproduce locomotor trajectories with a high level of realism. Finally, we compared trajectories resulting from the proposed model with real ones in complex situations (that differ from the experimental data used for the elaboration of the model).

Figure 12. A crowd of Virtual Humans navigating in a large virtual environment using crowd patches

We also addressed the problem of populating large environments with numerous virtual humans (see Figure 12). We considered the specific case of interactive virtual environments, where both simulation and rendering of the scene must be achieved in real time in order to allow interactivity with users. As a result, available computation time for achieving simulation is extremely small, few tens of milliseconds. We developed a technique called *crowd patches* which solves this problem by allowing the pre-computation of major parts of the simulation tasks: we are then able to reduce drastically the proportion of computations dedicated to simulation, with improved realism. This work was realized in collaboration with EPFL-VRlab.

Finally, we are currently developing this experimental framework in collaboration with the CAD&CG laboratory from the Zhejiang University in China. The objective is to make possible the immersion of a real user into a mixed reality scene where virtual pedestrians navigate among real obstacles, static or dynamic.

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

Participants: Bruno Arnaldi, Stéphanie Gerbaud.

We have proposed models to extend the possibilities of a virtual environment for training (GVT [37], see section 5.5) to training on collaborative procedures where real users and virtual humans collaborate. First an activity model for the actors allows the dynamic substitution of a real user by a virtual human. This model makes an actor perform actions depending on his characteristics, on the scenario, on the environment and also on his partners' activities. We have also extended the scenario language LORA in order to describe collaborative scenarios. Such a scenario describes the assignment of people to actions and integrates some collaborative actions. The scenario has been simplified while making some basic actions implicit such taking or putting back an object. Finally, we developed an action selection mechanism [36]. Its aim is dual: to enable a virtual human to select an action to perform and to give some pedagogical advice to a trainee about the best action to choose. This mechanism is divided in two parts. The first one is a global module, the action distribution module, in charge of ranking the candidates for each scenario action. The second part consists in one decisional module per actor which uses the actor's collaborative profile (a set of behavioral rules) and the suggestion made by the action distribution module to choose the next action to perform. An actor will then use his collaborative profile (a set of behavioral rules) and the suggestion made by the action distribution module to choose the next action to perform. These models (detailed in [10]) have been integrated to GVT in a prototype and validated thanks to an applicative scenario which consists in collaboratively assembling a piece of furniture delivered in a kit. This scenario also demonstrates interesting properties of the action selection mechanism such as adaptation of a virtual human to the trainee's actions or implicit collaboration.

6.20. Through-The-Lens Scene Design

Keywords: *Camera Control*, *Scene Design*, *Through-The-Lens Interaction*.

Participant: Marc Christie [contact].

The increasing demand in creating and composing nice views of 3D scenes stimulates the need for better editing tools that can emphasize on both composition and aesthetics through more intuitive manipulation tools. Classical approaches rely on 4-split view displays and generic manipulation tools such as arcballs and translation arrows to manipulate the content of the scene as well as the camera and lights. However such tools are cumbersome when fine modifications are required on the picture to enforce composition, balance and unit rules.

In this work, we propose to rely on the Through-the-Lens interaction metaphor to directly control the content of the 3D scene, through the 2D screen. We provide 2D manipulation primitives to enforce composition rules, and detail techniques to manipulate the camera, the objects and the lights by controlling their projected properties on the screen (vertices, specular lights, shadows).

The 2D primitives express non-linear relations with the 3D components of the scene, and we formulate the process as an optimisation problem which determines the optimal parameter transformations. Contributions of this approach are threefold:

- we propose a unified framework to manipulate simultaneously multiple features (camera, object and light parameters);
- we propose the use of composition primitives to assist the enforcement of composition rules;
- we propose a novel ellipse-based approach for inverse lighting through the screen.

The first results [56] demonstrate the technical feasabililty of the approach.

6.21. Occlusion-free Camera Control

Keywords: *Camera Control*, *Virtual Camera Planning*, *Visibility Computation*.

Participant: Marc Christie [contact].

Computing and maintaining the visibility of moving targets in a complex virtual environment is a critical task (see our state of the art on the domain [13]). Classical techniques idealise the occluders and targets models, and provide only partial solution to the problem (*e.g.* by restricting to a single moving target). In this work, we propose a novel approach to the real-time evaluation of the visibility of multiple targets, while maintaning camera coherency. We compute a sampling inside a restricted area around the camera and evaluate through hardware rendering the visibility of the targets for each sample. A temporal window aggregates the visibility information to damper the camera mouvements (*i.e.* reduce over-reactivity due to fast and sparse occluders). Next, in order to evaluate the degree of occlusion of the visual extent of targets, the process switches targets points on the surface of objects in a stochastic way.

Results show that the sampling and the camera move can be performed in less than $3ms$ per each frame without resorting to any optimisation or shader implementation [65]. Furthermore, the choice of the next camera move within the occlusion-free samples can be extended by evaluating classical cinematographic properties (size of targets, vantage points, framing).

6.22. Interval Constraint-based search techniques

Keywords: *Max-CSP*, *Numerical Constraint Programming*, *Numerical Tabu Search*.

Participant: Marc Christie [contact].

The Constraint Satisfaction Problem (CSP) framework provides a powerful and efficient framework for modeling and solving problems that are well defined. However, for a number of problems that occur for example in design, chemistry or computer graphics, over-constrained systems are commonplace: the modelling of a constraint system is an incremental task, and a 'no solution' answer offers no cues on how to change the model. Though litterature details how such over-constrained systems can be handled for discrete domains, no techniques have been explored for continuous domain. In this work, we propose a Branch-and-Bound algorithm to compute solutions of Numerical Max-CSP that maximises the constraint satisfaction [48] (this paper has received the best PhD student paper at Constraint Programming Conference 2008). The algorithm has been applied to different problems of virtual camera control in computer graphics and in all cases outperforms previous techniques.

6.23. Gesture Analysis

Keywords: *Gesture Analysis*, *Segmentation*, *Sign Language*.

Participants: Sylvie Gibet, Alexis Héloir.

One major problem in representing gesture from recorded data is that these data are multidimensional and direct use of them is rather expensive and fastidious. Another problem is the lack of flexibility. Computing motion from real motion chunks necessi-tates indeed the elaboration of large data sets, and the development of data-driven methods for tracking, adapting or generating new motion. Finally, finding the best motion representation is a central problem, depending on the application. As these processes operate on multidimensional data, one way to characterize gesture is to compress the original information into relevant samples and to use this data reduction to efficiently retrieve or reconstruct the motion, or to identify meaningful motion units. The automatic extraction of key frames (postures or key points) is also an efficient way to synthesize new gestures, which takes into account the spatial variability of gestures and the co-articulation effects.

We consider captured data consisting of sampled trajectories that characterize the evolution with time of the position and orientation of the human joints. For human gestures, these joint trajectories present specific profiles that can be readable through the analysis of shape (curvature) and kinematics (velocity). In particular variations in velocity are responsible for the aggregation of samples in some areas of the trajectories. We use an adaptive sub-sampling algorithm, called DPPLA (Dynamic Programming Piecewise Linear Approximation), which identifies in an optimal manner a set of targets located on the trajectories. This target-based representation of trajectories is applied to automatic segmentation of 3D arm end-point trajectories and to motion reconstruction using inverse kinematics [38].

Sign Language gestures have been automatically segmented according to a curvature and velocity approximation [39]. A qualitative segmentation has also been realized on sentences of French sign language, showing the influence of style on the structural organisation of some lexical units [41]. Finally, we proposed a formalism to describe Sign Language phonology for generation purpose [22].

7. Contracts and Grants with Industry

7.1. Nexter: Generic Virtual Training

Participants: Bruno Arnaldi, Xavier Larrodé, Stéphanie Gerbaud, Valérie Gouranton.

The GVT (Generic Virtual Training) project (INRIA, Nexter-group and ENIB) is a very challenging one. Indeed, in this project, we introduce advanced VR technology in order to produce customizable VR applications dedicated to industrial training. GVT is based on OpenMASK [42], the VR-platform of the Bunraku team (INRIA), and AReVi (ENIB-Li2 VR-platform). All our developments are totally re-usable in industrial training, and are not dedicated to a particular industrial equipment and procedure. While our partner ENIB is concerned by the pedagogic part of the training, we focus our activity into the following points. First the design of true reactive 3D objects (including complex objects such as virtual humans) with embedded behaviors thanks to the STORM model. Then the design of high level specification language, LORA, in order to describe complex and potentially collaborative human activity (virtual activity in relationship with the real activity). Afterwards the design of an author-tool, based on STORM and LORA, to create scenarios by demonstration. And last the design of tools to support collaborative aspects of the training and especially a mechanism able to suggest in a given context, the best candidate for an action. You can find more information on this last point in the "new results" section. The main goal of this overall project is to produce a real application in order to validate all the new concepts we introduce. The scientific contributions of this application have been presented this year in the international conference IEEE-VR [37] and the application has already been shown at different meetings: Eurosatory, Le Bourget, Laval-Virtual, AFRV days and Intuition workshop. The GVT project lead to the deposit of 5 french patents and 1 European patent, and 2 PhD have been defended, including one this year [10]. More information on the product can be found in section 5.5.

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

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

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

OpenViBE is a 3-year project funded by the French National Agency for Research. The aims of the Open-ViBE project are : (1) to conduct research in the area of Brain-Computer Interfaces and Virtual Reality, and (2) to develop an open-source software environment enclosing novel and efficient techniques for Brain-Computer Interfaces. The two main innovations that the Open-ViBE project focuses are : (1) new techniques for processing and identification of cerebral data based on neurophysiological experimentations that will identify the best physiological indicators (using real-time EEG-based source localisation techniques), and (2) new techniques to send back information to the user of the BCI about his/her mental activity (using Virtual Reality technologies: i.e. audio, visual and haptic feedback), which could then be used to improve the learning and the control of the mental activity.

Open-ViBE involves 6 partners: INRIA/BUNRAKU (Virtual Reality), INSERM (Neurophysiology), FRANCE TELECOM (Multimedia applications), INPG-GIPSALab (signal processing), CEA (signal processing) and AFM (evaluation with disabled people). Our consortium focuses on multimedia applications (video games, theme parks) and medical applications, devoted notably to disabled people (re-education, therapy, assistance, accessibility). In the end, the Open-ViBE project must lead to an open-source software distributed over the internet (gforge INRIA). Three demonstrators will also be built to illustrate the numerous possibilities of our technology, in the field of multimedia and assistance to disabled people. More information can be found on the OpenViBE website : http://www.irisa.fr/bunraku/OpenViBE

7.3. ANR PACMAN: Haptic Perception and Interaction at Nanoscopic Scale

Keywords: *Haptic interaction*, *Microscopic*, *Nanoscopic*, *Perception*, *Teleoperation*.

Participants: Anatole Lécuyer, Zhan Gao.

PACMAN is a 3-year project funded by the French National Agency for Research. PACMAN involves 3 partners: INRIA/BUNRAKU (Virtual Reality), LRP (Robotics/haptics), and CEA (Robotics/haptics). The objective of the PACMAN project is to study the haptic perception and interaction at microscopic and nanoscopic scales. PACMAN intends to deliver novel findings in the area of human haptic perception (understanding and learning of nanophysics phenomena, with and without haptic feedback), as well as novel technologies (novel haptic devices more adapted to the characteristics of haptic interaction at microscopic and nanoscopic scales).

7.4. PERF-RV2

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

Participants: Julien Bilavarn, Stéphane Donikian [contact], Fabrice Lamarche, Alexandre Pillon, 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, behavioral level, interaction between a human operator and a 3D environment, scenario authoring of the human experience. We are participating to all four workpackages and leading two of them concerning human behaviour and scenario authoring.

7.5. Part@ge

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

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

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

- Models and Objects for Collaborative Virtual Environments,
- Communication and Presence,
- Advanced Collaboration,
- Integration, Usability and Evaluation.

We are leading the project, participating to the four work packages and we leading one of them related to advanced collaboration. The Part@ge project is based on OpenMASK (our VR-platform), Spin3D (the FT R&D VR-platform) and Virtools. We have also collaborated with the ANR Project SCOS, around 3D visualisation of scientific data (results of scientific calculations upon physical data) and 3D collaboration between several users working with these results. This common work has lead to a prototype that has been presented at the Laval Virtual and Nem Summit manifestations, and at the VRST'2008 conference.

7.6. SignCom

Keywords: *Animation*, *Communication with Virtual Character*, *Motion Recognition*, *Sign Language*.

Participants: Stéphane Donikian, Sylvie Gibet [contact].

SignCom aims to improve the quality of the real-time interaction between real humans and virtual agents, by exploiting natural communication modalities such as gestures, facial expressions and gaze direction. Based on gestural languages highly structured and coded, the real and virtual humans produce statements towards their interlocutor through a dialog model. Gestures of the user, previously recorded by motion capture techniques, are used on the one hand to facilitate the vision-based recognition of gestures in real-time, and on the other hand to drive the character's animation. The final objective of the project consists in elaborating an innovative and multimodal interactive application, producing new ways of communication by means of smooth and expressive gestures. The communication is done in the two directions through an interactive mechanism: the user carries out gestures which are recognized by the system. The virtual agent provides answers after interpretation of the emitted actions. The interaction is guided by the progressive construction of a virtual space of dialogue between the real and virtual human. This construction of a spatio-temporal virtual scene is based on mechanisms used in sign languages. These very structured languages use indeed a visual support of communication and define space referents to build a narration scene. Moreover, they have the specificity "to say while showing", which give a strong dimension of iconicity, relevant within the framework of gestures and spatial expressions.

SignCom is a partnership between VALORIA lab. (University of Bretagne Sud, Vannes), IRIT lab. (Toulouse), M2S lab. (University of Rennes 2), and Bunraku team (IRISA), Polymorph Software firm, and WebSourd firm (as external providers).

7.7. "System@tic": Digital Plant 2

Participants: Stéphane Donikian [contact], Fabrice Lamarche [contact], Yann Pinczon du Sel, Bathélémy Serres.

"Digital plant 2" is a 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 currently working in the work package entitled "Human modeling".

The goal of this workpackage is to propose techniques to automatically handle path finding and navigation within virtual plants and to provide toolkits to describe the behavior of virtual humans. The proposed solution is to integrate several of our tools within Virtools (a software designed to add script based comportments to virtual objets). Firstly, TopoPlan 5.6 has been integrated to automatically analyse the topology of a 3D database describing the simulation environment. Secondly, TopoPlan Behavior 5.7, coupled with MKM 5.3 and HPTS++ 5.4, is used to handle the animation of a virtual human navigating within constrained environments previously analyzed by TopoPlan. We are currently working on the integration of HPTS++ within Virtools to provide a high level interface enabling the description of complex behaviours by combining atomic tasks (MKM actions and TopoPlan behaviours) through HPTS++ tasks operators.

Those results will be used to realize industrial scenarios provided by Dassault Systèmes and EADS within Virtools. Theses scenarios will focus on the assembly line of planes.

7.8. ANR Locanthrope

Keywords: *locomotion*, *motion planning*.

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

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

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

7.9. ANR Pedigree

Keywords: *crowd simulation*.

Participants: Julien Pettré [contact], Stephane Donikian.

Pedigree is a national project funded by the French Research Agency (ANR). The project is leaded by Pierre Degond, professor at the University Paul Sabatier in Toulouse (III). Partners are: Institut de Mathématiques de Toulouse (IMT) de l'Université Paul Sabatier de Toulouse, Centre de Recherche sur la Cognition Animale (CRCA) de l'Université de Toulouse, Laboratoire de Physique Théorique (LPT) de l'Université de Paris-Sud, et l'équipe-projet INRIA Bunraku de l'IRISA à Rennes.

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

8. Other Grants and Activities

8.1. NoE: Intuition

Participants: Bruno Arnaldi [contact], Anatole Lecuyer, 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 58 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.

INTUITION Network aims at (i) systematically acquiring and clustering 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; (ii) performing an initial review of existing and emerging VR systems and VE applications, and establish a framework of relevant problems and limitations to be overcome; and (iii) identifing user requirements and wishes and also new promising application fields for VR technologies.

Anatole Lécuyer is leading the "Haptic Interaction" Working Group (WG 2.10). Bruno Arnaldi and Yann Jehanneuf are the leaders of the "Business Office" (BO) Subtask (1.F.2) within the Work Package (WP1.F).

8.2. STREP: NIW

Keywords: *Foot*, *Haptic feedback*, *Sensation*, *Tactile*, *Walking*.

Participant: Anatole Lécuyer.

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

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

8.3. PHC "Alliance" Virtual Sports Training

Participants: Franck Multon [contact], Ludovic Hoyet.

This PHC "Alliance" program aims at encouraging collaborations between our lab. and Taku Komura (Edinburgh Univ.). It consists in funding shorts stays of French researchers in Edinburgh Univ. This project deals with developing virtual humans who are able to react to complex dynamic situations such as playing in sports. The character should be able to react in real-time to interactions with a user while taking dynamics into account. This project is linked to another PHC "Alliance" project proposed in University Rennes 2 (M2S lab. specialized in sports science) and Queen's Univ. Belfast (psychology school specialized in the perception-action loop). The main goal is to initiate collaborations and exchanges in order to submit a European FP7 project based on using VR for training subjects to improve their performance in sports.

9. Dissemination

9.1. Scientific Community Animation

- Anatole Lécuyer: **Associate editor** of ACM Transactions on Applied Perception, **Secretary** of the French Association for Virtual Reality, **Secretary** of the IEEE Technical Committee on Haptics, **Organizer** of Tutorial at IEEE Virtual Reality 2008 on "Integration of Haptics in Virtual Environments", **Keynote speaker** at WSCG 2008, **Program Committee member** of ACM VRST 2008, EGVE 2008, EMCS 2008, INTUITION 2008, VRIC 2008, **Reviewer of journals** IEEE TH, ACM TAP, Presence, VRJ, Haptics-e, **Reviewer of conferences** IEEE 3DUI, Eurographics, ACM VRST, Haptics Symposium, ACM/IEEE ISMAR, EGVE, ECMS, VRIC, INTUITION.
- Franck Multon: **Member** of the ACM SIGGRAPH, Eurographics, AFIG, French and European Society of Biomechanics associations, **Reviewer of journals** CAVWJournal of Biomechanics, Computer & Graphics, **Program Committee member** of GRAPP'2008, GRAPP'2009, CASA'2009, CASA'2009, IEEE-VR'2009, MIRAGE'2009, Annual congress of the French Society of Biomechanics'2009, **Scientific expert** for the ANR, **co-Program Chair** of "Virtual Reality & Sports" in Laval Virtual'2009, **invited keynote speaker** in MIRAGE'2009
- Georges Dumont: **Member** of the AFRV, **Reviewer** of ECMS 2008, ACM VRST 2008, ACM VRST, IDMME-VC 2008, **Program Committee member** of Virtual Concept 2008 (Vice chair) **Scientific expert** for ANR MDCA 2006 and MDCO 2007, **Session Chairman** during IDMME-Virtual Concept 2008
- Julien Pettré: **Reviewer** of IEEE CGA, IEEE ICRA, **Reviewer of Journal** of Zhejiang University-SCIENCE
- Chrisitan Bouville: **Member** of ACM-SIGGRAPH: C. Bouville, **Reviewer** of MMVE08, IEEE Computer Magazine, ACM WEB3D 2008 Symposium, Computer Graphics Forum, ISVC 2008, **Scientific Expert** as member of the Supervising Committee of PRIDES (Pôle Régional de Recherche en Images Données et Systèmes), **External examiner** of PhD candidate Guillaune François – University of Rennes 1, and Julien Lacoste – University of Pau.
- Kadi Bouatouch: **Member** of the programme committee of WSCG2008, Grapp'2008, Pacific Graphics'2008, ISVC'08, IWSV'08, **Member** of the Editorial Board of the Visual Computer Journal, **Reviewer** for most of all the computer graphics conferences (Siggraph, Eurographics, EGSR, etc.) and journals (IEEE TVCG, The Visual Computer, Computer Graphics Forum, JCST, TOG), **Responsible** for a collaboration with the computer graphics group of the University of Central Florida and the university of Utah, **External examiner** of multiple PhD committees in US and France.
- Marc Christie: **Member** of Eurographics, AFIG and AFRV, **Member** of Programme committee and Steering committee of Smartgraphics 2008, **External Examiner** of PhD Candidate Hai Nam Ha – University of Newcastle, **Reviewer** of SIGGRAPH 2008, SIGGRAPH ASIA 2008, Eurographics 2009, **Reviewer of journals** CAVW, **Invited Seminar** Univerity of Limoges.
- Maud Marchal: **Reviewer** of MICCAI'08, IEEE EMBC'08, Eurographics'09.

9.2. Courses in Universities

- R. Cozot: **Responsible** for the Digital Imaging and Communication Speciality (INC) in the IFSIC institute, MASTER MITIC (IFSIC), Video, Image and Sound, MASTER MITIC (IFSIC), Modelling, Animation and Rendering (with F. Lamarche), MASTER MITIC (IFSIC), Mobile Multimedia (with F. Lamarche).

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

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