



IN PARTNERSHIP WITH:
Université Rennes 1

**Université Haute Bretagne
(Rennes 2)**

**Ecole normale supérieure de
Rennes**

Activity Report 2013

Project-Team MIMETIC

Analysis-Synthesis Approach for Virtual Human Simulation

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA)

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Interaction and visualization

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Project-Team MIMETIC

Keywords: Virtual Human, Virtual Reality, Simulation, Computer Graphics, Perception

Creation of the Team: 2011 January 01, *updated into Project-Team:* 2014 January 01.

1. Members

Research Scientist

Julien Pettré [Inria, Researcher]

Faculty Members

Franck Multon [Team leader, Univ. Rennes II, Professor, HdR]

Benoit Bideau [Univ. Rennes II, Associate Professor, HdR]

Nicolas Bideau [Univ. Rennes II, Associate Professor]

Marc Christie [Univ. Rennes I, Associate Professor]

Armel Crétual [Univ. Rennes II, Associate Professor, HdR]

Georges Dumont [ENS Cachan, Professor, from Jan 2013, HdR]

Richard Kulpa [Univ. Rennes II, Associate Professor]

Fabrice Lamarche [Univ. Rennes I, Associate Professor]

Guillaume Nicolas [Univ. Rennes II, Associate Professor]

Charles Pontonnier [ENS Cachan, Associate Professor, from Jan 2013]

Engineers

Emmanuel Badier [Inria]

Julian Joseph [Inria, ADT ManIP, from Nov 2013]

Tristan Le Bouffant [Inria, ANR CHROME project, from Nov 2013]

Anne-Hélène Olivier [Inria, ANR CHROME project]

Orianne Siret [Univ. Rennes I, until Nov 2013]

PhD Students

Julien Bruneau [Univ. Rennes I, from Oct 2013]

Ana Lucia Cruz Ruiz [Inria, ANR ENTRACTE project, from Nov 2013]

Kevin Jordao [Inria, ANR CHROME project]

Carl-Johan Jorgensen [Univ. Rennes I]

Antoine Marin [Univ. Rennes II]

Jonathan Perrinet [Inria, ANR CHROME project, until Dec 2013]

Pierre Plantard [Rennes II, CIFRE, from Jan 2013]

Philippe Rannou [Univ. Rennes I]

Cunka Sanokho [Univ. Rennes I]

Steve Tonneau [INSA Rennes]

David Wolinski [Univ. Rennes I]

Hui-Yin Wu [Inria]

Post-Doctoral Fellows

Yi Li [Inria, ANR INSTITUT CARNOT ABDT project, until Mar 2013]

Christophe Lino [Inria, until Sep 2013]

Visiting Scientists

Amina Bouguetitiche [PhD Student, from Nov 2013 until Nov 2013]

Chieh-Jen Chen [Inria, from Jun 2013 until Sep 2013]

Alexandra Covaci [PhD Student, until Apr 2013]

Teófilo Dutra [PhD Student, from Sep 2013]

Francesco Grani [Assistant Professor, from Jul 2013 until Jul 2013]

Stephen Guy [Assistant Professor, from Feb 2013 until Mar 2013]

Administrative Assistant

Nathalie Denis [Univ. Rennes I, until Dec 2014]

2. Overall Objectives

2.1. Presentation

MimeTIC is a multidisciplinary team whose aim is to better understand and model human activity in order to simulate realistic autonomous virtual humans: realistic behavior, realistic motions and realistic interactions with other characters and users. It leads to modeling the complexity of a human body, his environment where he can pick-up information and he can act on it. A specific focus is dedicated to human physical activity and sports as it raises the highest constraints and the highest complexity when addressing these problems. Thus, MimeTIC is composed of experts in computer science whose research interests are computer animation, behavioral simulation, motion simulation, crowds and interaction between real and virtual humans. MimeTIC is also composed of experts in sports science, motion analysis, motion sensing, biomechanics and motion control. Hence, the scientific foundations of MimeTIC are motion sciences (biomechanics, motion control, perception-action coupling, motion analysis), computational geometry (modeling of the 3D environment, motion planning, path planning) and design of protocols in immersive environments (use of virtual reality facilities to analyze human activity).

Thanks to these skills, we wish to reach the following objectives: to make virtual human behave, move and interact in a natural manner in order to increase immersion and to improve knowledge on human motion control. In real situations (see Figure 1), people have to deal with their physiological, biomechanical and neurophysiological capabilities in order to reach a complex goal. Hence MimeTIC addresses the problem of modeling the anatomical, biomechanical and physiological properties of human being. Moreover this character has to deal with his environment. Firstly he has to perceive this environment and pick-up relevant information. MimeTIC thus addresses the problem of modeling the environment including its geometry and associated semantic information. Secondly, he has to act on this environment to reach his goal. It leads to cognitive processes, motion planning, joint coordination and force production in order to act on this environment.

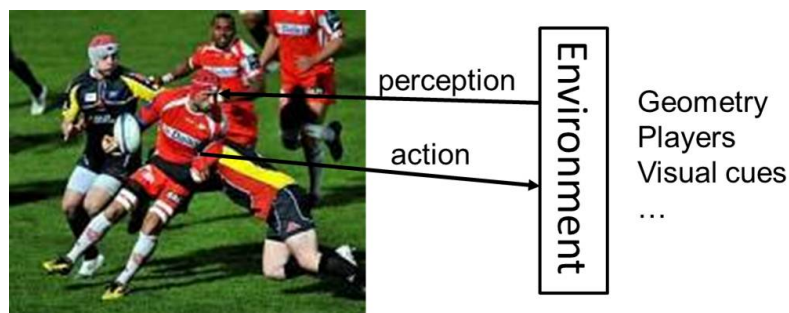


Figure 1. Main objective of MimeTIC: better understand human activity in order to better simulate virtual humans. It leads to modeling the complexity of human body, his environment where he can pick-up information and he can act on it.

In order to reach the above objectives, MimeTIC has to address three main challenges:

- dealing with the intrinsic complexity of human being, especially when addressing the problem of interactions between people for which it is impossible to predict and model all the possible states of the system,
- making the different components of human activity control (such as the biomechanical and physical, the reactive, cognitive, rational and social layers) interact while each of them is modeled with completely different states and time sampling,
- and being able to measure human activity while dealing with the compromise between ecological and controllable protocols, and to be able to extract relevant information in wide databases of information.

Contrary to many classical approaches in computer simulation, which mostly propose simulation without trying to understand how real people do, the team promotes a coupling between human activity analysis and synthesis, as shown in Figure 2.

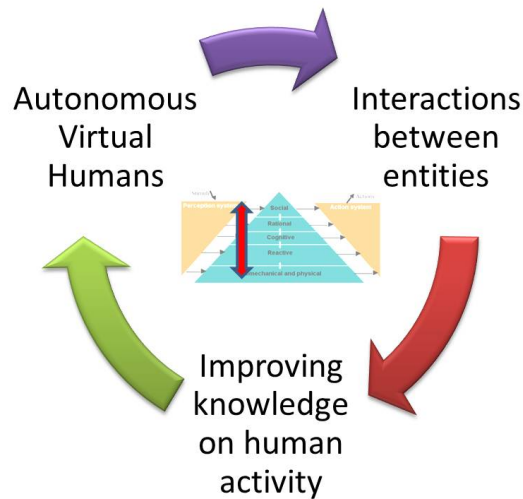


Figure 2. Research path of MimeTIC: coupling analysis and synthesis of human activity. Analysis provides us with more realistic autonomous characters and synthesis enables us to evaluate assumptions about human motion control.

In this research path, improving knowledge on human activity enables us to highlight fundamental assumptions about natural control of human activities. These contributions can be promoted in e.g. biomechanics, motion sciences, neurosciences. According to these assumptions we propose new algorithms for controlling autonomous virtual humans. The virtual humans can perceive their environment and decide of the most natural action to reach a given goal. This work is promoted in computer animation, virtual reality and has some applications in robotics through collaborations. Once autonomous virtual humans have the ability to act as real humans should do in the same situation, it is possible to make them interact with other autonomous characters (for crowds or group simulations) and with real users. The key idea here is to analyze to what extent the assumptions proposed at the first stage lead to natural interactions with real users. This process enables the validation of both our assumptions and our models.

Among all the problems and challenges described above, MimeTIC focuses on the following domains of research:

- motion sensing which is a key issue to extract information from raw motion capture systems and thus to propose assumptions on how people control their activity,
- human activity & virtual reality, which is explored through sports application in MimeTIC. This domain enables the design of new methods for analyzing the perception-action coupling in human activity, and to validate whether the autonomous characters lead to natural interactions with users,
- crowds and groups simulation which is dedicated to model the interactions in small groups of individuals and to see how to extend to larger groups, such as crowds with lot of individual variability,
- virtual storytelling which enables us to design and simulate complex scenarios involving several humans who have to satisfy numerous complex constraints (such as adapting to the real-time environment in order to play an imposed scenario), and to design the coupling with the camera scenario to provide the user with a real cinematographic experience,
- biomechanics which is essential to offer autonomous virtual humans who can react to physical constraints in order to reach high-level goals, such as maintaining balance in dynamic situation or selecting a natural motor behavior among all the theoretical solution space for a given task,
- and autonomous characters which is a transversal domain that can reuse the results of all the other domains to make these heterogeneous assumptions and models provide the character with natural behaviors and autonomy.

2.2. Highlights of the Year

Finalist of best manipulation paper award in ICRA 2013 for the paper entitled: .

Best Paper Award in IEEE Coginfocom 2013 for the paper entitled:

BEST PAPERS AWARDS :

[24] Fast Grasp Planning by Using Cord Geometry to Find Grasping Points in IEEE International Conference on Robotics and Automation ICRA. Y. LI, J.-P. SAUT, A. SAHBANI, P. BIDAUD, J. PETTRÉ, F. MULTON.

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

3. Research Program

3.1. Biomechanics and Motion Control

Human motion control is a very complex phenomenon that involves several layered systems, as shown in Figure 3. Each layer of this controller is responsible for dealing with perceptual stimuli in order to decide the actions that should be applied to the human body and his environment. Due to the intrinsic complexity of the information (internal representation of the body and mental state, external representation of the environment) used to perform this task, it is almost impossible to model all the possible states of the system. Even for simple problems, there generally exist infinity of solutions. For example, from the biomechanical point of view, there are much more actuators (i.e. muscles) than degrees of freedom leading to infinity of muscle activation patterns for a unique joint rotation. From the reactive point of view there exist infinity of paths to avoid a given obstacle in navigation tasks. At each layer, the key problem is to understand how people select one solution among these infinite state spaces. Several scientific domains have addressed this problem with specific points of view, such as physiology, biomechanics, neurosciences and psychology.

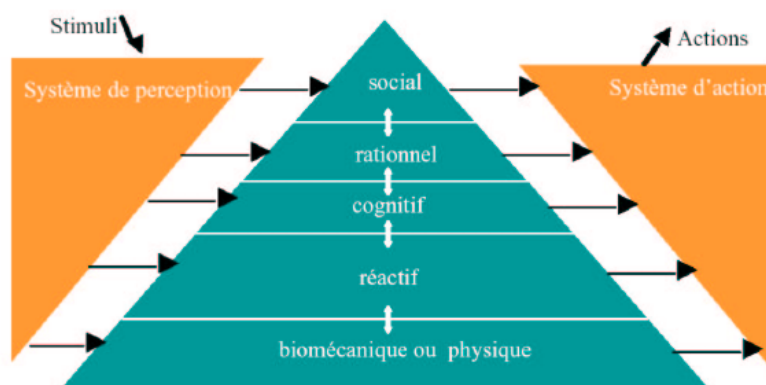


Figure 3. Layers of the motion control natural system in humans.

In biomechanics and physiology, researchers have proposed hypotheses based on accurate joint modeling (to identify the real anatomical rotational axes), energy minimization, force and torques minimization, comfort maximization (i.e. avoiding joint limits), and physiological limitations in muscle force production. All these constraints have been used in optimal controllers to simulate natural motions. The main problem is thus to define how these constraints are composed altogether such as searching the weights used to linearly combine these criteria in order to generate a natural motion. Musculoskeletal models are stereotyped examples for which there exist infinity of muscle activation patterns, especially when dealing with antagonist muscles. An unresolved problem is to define how using the above criteria to retrieve the actual activation patterns while optimization approaches still lead to unrealistic ones. It is still an open problem that will require multidisciplinary skills including computer simulation, constraint solving, biomechanics, optimal control, physiology and neurosciences.

In neuroscience, researchers have proposed other theories, such as coordination patterns between joints driven by simplifications of the variables used to control the motion. The key idea is to assume that instead of controlling all the degrees of freedom, people control higher level variables which correspond to combination of joint angles. In walking, data reduction techniques such as Principal Component Analysis have shown that lower-limb joint angles are generally projected on a unique plan whose angle in the state space is associated with energy expenditure. Although there exist knowledge on specific motion, such as locomotion or grasping, this type of approach is still difficult to generalize. The key problem is that many variables are coupled and it is very difficult to objectively study the behavior of a unique variable in various motor tasks. Computer simulation is a promising method to evaluate such type of assumptions as it enables to accurately control all the variables and to check if it leads to natural movements.

Neurosciences also address the problem of coupling perception and action by providing control laws based on visual cues (or any other senses), such as determining how the optical flow is used to control direction in navigation tasks, while dealing with collision avoidance or interception. Coupling of the control variables is enhanced in this case as the state of the body is enriched by the big amount of external information that the subject can use. Virtual environments inhabited with autonomous characters whose behavior is driven by motion control assumptions is a promising approach to solve this problem. For example, an interesting problem in this field is navigation in an environment inhabited with other people. Typically, avoiding static obstacles together with other people displacing into the environment is a combinatory problem that strongly relies on the coupling between perception and action.

One of the main objectives of MimeTIC is to enhance knowledge on human motion control by developing innovative experiments based on computer simulation and immersive environments. To this end, designing experimental protocols is a key point and some of the researchers in MimeTIC have developed this skill in biomechanics and perception-action coupling. Associating these researchers to experts in virtual human simulation, computational geometry and constraints solving enable us to contribute to enhance fundamental knowledge in human motion control.

3.2. Experiments in Virtual Reality

Understanding interaction between humans is very challenging because it addresses many complex phenomena including perception, decision-making, cognition and social behaviors. Moreover, all these phenomena are difficult to isolate in real situations, it is thus very complex to understand the influence of each of them on the interaction. It is then necessary to find an alternative solution that can standardize the experiments and that allows the modification of only one parameter at a time. Video was first used since the displayed experiment is perfectly repeatable and cut-offs (stop the video at a specific time before its end) allow having temporal information. Nevertheless, the absence of adapted viewpoint and stereoscopic vision does not provide depth information that are very meaningful. Moreover, during video recording session, the real human is acting in front of a camera and not an opponent. The interaction is then not a real interaction between humans.

Virtual Reality (VR) systems allow full standardization of the experimental situations and the complete control of the virtual environment. It is then possible to modify only one parameter at a time and observe its influence on the perception of the immersed subject. VR can then be used to understand what information are picked up to make a decision. Moreover, cut-offs can also be used to obtain temporal information about when these information are picked up. When the subject can moreover react as in real situation, his movement (captured in real time) provides information about his reactions to the modified parameter. Not only is the perception studied, but the complete perception-action loop. Perception and action are indeed coupled and influence each other as suggested by Gibson in 1979.

Finally, VR allows the validation of the virtual human models. Some models are indeed based on the interaction between the virtual character and the other humans, such as a walking model. In that case, there are two ways to validate it. First, they can be compared to real data (e.g. real trajectories of pedestrians). But such data are not always available and are difficult to get. The alternative solution is then to use VR. The validation of the realism of the model is then done by immersing a real subject in a virtual environment in which a virtual character is controlled by the model. Its evaluation is then deduced from how the immersed subject reacts when interacting with the model and how realistic he feels the virtual character is.

3.3. Computational Geometry

Computational geometry is a branch of computer science devoted to the study of algorithms which can be stated in terms of geometry. It aims at studying algorithms for combinatorial, topological and metric problems concerning sets of points in Euclidian spaces. Combinatorial computational geometry focuses on three main problem classes: static problems, geometric query problems and dynamic problems.

In static problems, some input is given and the corresponding output needs to be constructed or found. Such problems include linear programming, Delaunay triangulations, and Euclidian shortest paths for instance. In geometric query problems, commonly known as geometric search problems, the input consists of two parts: the search space part and the query part, which varies over the problem instances. The search space typically needs to be preprocessed, in a way that multiple queries can be answered efficiently. Some typical problems are range searching, point location in a partitioned space, nearest neighbor queries for instance. In dynamic problems, the goal is to find an efficient algorithm for finding a solution repeatedly after each incremental modification of the input data (addition, deletion or motion of input geometric elements). Algorithms for problems of this type typically involve dynamic data structures. Both of previous problem types can be converted into a dynamic problem, for instance, maintaining a Delaunay triangulation between moving points.

The Mimetic team works on problems such as crowd simulation, spatial analysis, path and motion planning in static and dynamic environments, camera planning with visibility constraints for instance. The core of those problems, by nature, relies on problems and techniques belonging to computational geometry. Proposed models pay attention to algorithms complexity to be compatible with performance constraints imposed by interactive applications.

4. Application Domains

4.1. Autonomous Characters

Autonomous characters are becoming more and more popular as they are used in an increasing number of application domains. In the field of special effects, virtual characters are used to replace secondary actors and generate highly populated scenes that would be hard and costly to produce with real actors. In video games and virtual storytelling, autonomous characters play the role of actors that are driven by a scenario. Their autonomy allows them to react to unpredictable user interactions and adapt their behavior accordingly. In the field of simulation, autonomous characters are used to simulate the behavior of humans in different kind of situations. They enable to study new situations and their possible outcomes.

One of the main challenges in the field of autonomous characters is to provide a unified architecture for the modeling of their behavior. This architecture includes perception, action and decisional parts. This decisional part needs to mix different kinds of models, acting at different time scale and working with different nature of data, ranging from numerical (motion control, reactive behaviors) to symbolic (goal oriented behaviors, reasoning about actions and changes).

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

4.2. Biomechanics and Motion Analysis

Biomechanics is obviously a very large domain. This large set can be divided regarding to the scale at which the analysis is performed going from microscopic evaluation of biological tissues' mechanical properties to macroscopic analysis and modeling of whole body motion. Our topics in the domain of biomechanics mainly lie within this last scope.

The first goal of such kind of research projects is a better understanding of human motion. The MimeTic team addresses three different situations: everyday motions of a lambda subject, locomotion of pathological subjects and sports gesture.

In the first set, Mimetic is interested in studying how subjects maintain their balance in highly dynamic conditions. Until now, balance have nearly always been considered in static or quasi-static conditions. The knowledge of much more dynamic cases still has to be improved. Our approach has demonstrated that first of all, the question of the parameter that will allow to do this is still open. We have also taken interest into collision avoidance between two pedestrian. This topic includes the research of the parameters that are interactively controlled and the study of each one's role within this interaction.

When patients, in particular those suffering from central nervous system affection, cannot have an efficient walking it becomes very useful for practitioners to benefit from an objective evaluation of their capacities. To propose such help to patients following, we have developed two complementary indices, one based on kinematics and the other one on muscles activations. One major point of our research is that such indices are usually only developed for children whereas adults with these affections are much more numerous.

Finally, in sports, where gesture can be considered, in some way, as abnormal, the goal is more precisely to understand the determinants of performance. This could then be used to improve training programs or devices. Two different sports have been studied: the tennis serve, where the goal was to understand the contribution of each segments of the body in ball's speed and the influence of the mechanical characteristics of the fin in fin swimming.

After having improved the knowledge of these different gestures a second goal is then to propose modeling solutions that can be used in VR environments for other research topics within MimeTic. This has been the case, for example, for the collision avoidance.

4.3. Crowds

Crowd simulation is a very active and concurrent domain. Various disciplines are interested in crowds modeling and simulation: Mathematics, Cognitive Sciences, Physics, Computer Graphics, etc. The reason for this large interest is that crowd simulation raise fascinating challenges.

At first, crowd can be first seen as a complex system: numerous local interactions occur between its elements and results into macroscopic emergent phenomena. Interactions are of various nature and are undergoing various factors as well. Physical factors are crucial as a crowd gathers by definition numerous moving people with a certain level of density. But sociological, cultural and psychological factors are important as well, since crowd behavior is deeply changed from country to country, or depending on the considered situations.

On the computational point of view, crowd push traditional simulation algorithms to their limit. An element of a crowd is subject to interact with any other element belonging the same crowd, a naive simulation algorithm has a quadratic complexity. Specific strategies are set to face such a difficulty: level-of-detail techniques enable scaling large crowd simulation and reach real-time solutions.

MimeTIC is an international key contributor in the domain of crowd simulation. Our approach is specific and based on three axis. First, our modeling approach is founded on human movement science: we conducted challenging experiment on the motion of groups. Second: we developed high-performance solutions for crowd simulation. Third, we develop solutions for realistic navigation in virtual world to enable interaction with crowds in Virtual Reality.

4.4. Motion Sensing

Recording human activity is a key point of many applications and fundamental works. Numerous sensors and systems have been proposed to measure positions, angles or accelerations of the user's body parts. Whatever the system is, one of the main is to be able to automatically recognize and analyze the user's performance according to poor and noisy signals. Human activity and motion are subject to variability: intra-variability due to space and time variations of a given motion, but also inter-variability due to different styles and anthropometric dimensions. MimeTIC has addressed the above problems in two main directions.

Firstly, we have studied how to recognize and quantify motions performed by a user when using accurate systems such as Vicon (product of Oxford Metrics) or Optitrack (product of Natural Point) motion capture systems. These systems provide large vectors of accurate information. Due to the size of the state vector (all the degrees of freedom) the challenge is to find the compact information (named features) that enables the automatic system to recognize the performance of the user. Whatever the method is used, finding these relevant features that are not sensitive to intra-individual and inter-individual variability is a challenge. Some researchers have proposed to manually edit these features (such as a Boolean value stating if the arm is moving forward or backward) so that the expertise of the designer is directly linked with the success ratio. Many proposals for generic features have been proposed, such as using Laban notation which was introduced to encode dancing motions. Other approaches tend to use machine learning to automatically extract these features. However most of the proposed approaches were used to seek a database for motions which properties correspond to the features of the user's performance (named motion retrieval approaches). This does not ensure the retrieval of the exact performance of the user but a set of motions with similar properties.

Secondly, we wish to find alternatives to the above approach which is based on analyzing accurate and complete knowledge on joint angles and positions. Hence new sensors, such as depth-cameras (Kinect, product of Microsoft) provide us with very noisy joint information but also with the surface of the user. Classical approaches would try to fit a skeleton into the surface in order to compute joint angles which, again, lead to large state vectors. An alternative would be to extract relevant information directly from the raw data, such as the surface provided by depth cameras. The key problem is that the nature of these data may be very different from classical representation of human performance. In MimeTIC, we try to address this problem in specific application domains that require picking specific information, such as gait asymmetry or regularity for clinical analysis of human walking.

4.5. VR and Sports

Sport is characterized by complex displacements and motions. These motions are dependent on visual information that the athlete can pick up in his environment, including the opponent's actions. The perception is thus fundamental to the performance. Indeed, a sportive action, as unique, complex and often limited in time, requires a selective gathering of information. This perception is often seen as a prerogative for action, it then takes the role of a passive collector of information. However, as mentioned by Gibson in 1979, the perception-action relationship should not be considered sequential but rather as a coupling: we perceive to act but we must act to perceive. There would thus be laws of coupling between the informational variables available in the environment and the motor responses of a subject. In other words, athletes have the ability to directly perceive the opportunities of action directly from the environment. Whichever school of thought considered, VR offers new perspectives to address these concepts by complementary using real time motion capture of the immersed athlete.

In addition to better understanding sports and interaction between athletes, VR can also be used as a training environment as it can provide complementary tools to coaches. It is indeed possible to add visual or auditory information to better train an athlete. The knowledge found in perceptual experiments can be for example used to highlight the body parts that are important to look at to correctly anticipate the opponent's action.

4.6. Interactive Digital Storytelling

Interactive digital storytelling, including novel forms of edutainment and serious games, provides access to social and human themes through stories which can take various forms and contains opportunities for massively enhancing the possibilities of interactive entertainment, computer games and digital applications. It provides chances for redefining the experience of narrative through interactive simulations of computer-generated story worlds and opens many challenging questions at the overlap between computational narratives, autonomous behaviours, interactive control, content generation and authoring tools.

Of particular interest for the Mimetic research team, virtual storytelling triggers challenging opportunities in providing effective models for enforcing autonomous behaviours for characters in complex 3D environments. Offering both low-level capacities to characters such as perceiving the environments, interacting with the environment and reacting to changes in the topology, on which to build higher-levels such as modelling abstract representations for efficient reasoning, planning paths and activities, modelling cognitive states and behaviours requires the provision of expressive, multi-level and efficient computational models. Furthermore virtual storytelling requires the seamless control of the balance between the autonomy of characters and the unfolding of the story through the narrative discourse. Virtual storytelling also raises challenging questions on the conveyance of a narrative through interactive or automated control of the cinematography (how to stage the characters, the lights and the cameras). For example, estimating visibility of key subjects, or performing motion planning for cameras and lights are central issues for which have not received satisfactory answers in the literature.

4.7. VR and Ergonomics

The design of workstations nowadays tends to include assessment steps in a Virtual Environment (VE) to evaluate ergonomic features. This approach is more cost-effective and convenient since working directly on the Digital Mock-Up (DMU) in a VE is preferable to constructing a real physical mock-up in a Real Environment (RE). This is substantiated by the fact that a Virtual Reality (VR) set-up can be easily modified, enabling quick adjustments of the workstation design. Indeed, the aim of integrating ergonomics evaluation tools in VE is to facilitate the design process, enhance the design efficiency, and reduce the costs.

The development of such platforms ask for several improvements in the field of motion analysis and VR: the interactions have to be as fidelistic as possible to properly mimic the motions performed in real environments, the fidelity of the simulator need also to be correctly evaluated, and motion analysis tools have to be able to provide in real-time biomechanics quantities usable by ergonomists to analyse and improve the working conditions.

5. Software and Platforms

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

Participant: Fabrice Lamarche [contact].

APP deposit number: IDDN.FR.001.290017.000.S.P.2003.000.10400

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

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

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

5.2. MKM: Manageable Kinematic Motions

Participants: Richard Kulpa [contact], Franck Multon.

APP deposit numbers: IDDN.FR.000.290016.001.S.A.2003.000.41200, IDDN.FR.001.290016.001.S.A.2003.000.41200 et IDDN.FR.002.290016.001.S.A.2003.000.41200

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

In this software, we propose a morphology-independent representation of the motion that is based on a simplified skeleton which normalizes the global postural 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. This approach dramatically reduces the post production time and allows the animators to handle a general motion library instead of one library per avatar.

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

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

All these features have been used to anticipate and control the placement of footprints depending on high level parameters. This link between control and behavior levels will be used for reactive navigation in order to have realistic motion adaptations as well as to deal with constrained environments.

5.3. TopoPlan: Topological Planner and Behaviour Library

Participant: Fabrice Lamarche [contact].

APP deposit numbers: FR.001.480016.00.S.P.2008.000.41200

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

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

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

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

6. New Results

6.1. Biomechanics and Motion Analysis

6.1.1. Modeling gesture in sports: tennis serve

Participants: Nicolas Bideau, Guillaume Nicolas, Benoit Bideau, Richard Kulpa.

In the midst of the INSEP project and the PhD of Caroline Martin, the tennis serve has been studied with biomechanical analyses. To this end, we have done kinematic and dynamic analyses based on motion capture, force plate and electromyographic systems. They provided information on how the gesture is performed and how it is related to injuries. Moreover, these analyses have been done on several level of players including top-level ones. A comparison of the kinematic and dynamic data can then be done. Our objective is to use these data in virtual reality to study the interaction between a tennis server and a receiver. We are creating a tool that displays a virtual server in front of a real receiver. The control of the virtual server is then done based on these biomechanical data. The objective is to analyze the reaction of the receiver depending on the movement of the server and its level of expertise.

6.1.2. Motion modeling in clinical applications

Participant: Armel Crétual.

We have developed a new index of gait quantification based on muscular activity called KeR-EGI. After having proved that this index is consistent and complementary with kinematics-based indices, we have shown that it is reproducible in patients even when their impairment level is high. This index is now used in clinical routine in adults. It will be also used in pediatrics in the next few months.

In orthopedics, we have proposed a novel method to quantify shoulder's global mobility called SCSV. It is based on the reachable volume in the whole configuration space of the shoulder, i.e. a 3-dimensional angular space. Clinical evaluations of shoulder's range of motion are quite always based on the analysis of only one axis, and the most usual refers to maximal external rotation from rest posture (ER1). Considering several mono-axial amplitudes, we have shown that ER1 is actually the worst choice to estimate global mobility. Instead of the ER1 procedure, we proposed to use the sum of 3 mono-axial amplitudes: external/internal amplitude at 90° lateral elevation, abduction and flexion/extension.

As shoulder is actually a complex of three articulations (gleno-humeral, scapulo-thoracic and sternoclavicular), we have evaluated the contribution of each of them on global mobility. This has been done through a cadaveric study where we measured SCSV in any possible blocking conditions of these three articulations (from 0 to 3).

6.2. VR and Ergonomics

Participants: Charles Pontonnier [contact], Georges Dumont, Franck Multon, Pierre Plantard.

The use of virtual reality tools for ergonomics applications is a very important challenge in order to generalize the use of such devices for the design of workstations.

First, the development of motion analysis tools is mandatory in order to provide additional information to the ergonomists and help them to analyse the work environment. Particularly, an analysis of the muscle forces involved in the motion generation is a very important information with regard to the ergonomics of a task. Several methods can lead to an estimation of these muscle forces. In a study we developed, we tried to assess the level of confidence for results obtained with an inverse dynamics method from real captured work tasks. The chosen tasks were meat cutting tasks, well known to be highly correlated to musculoskeletal troubles appearance in the slaughter industry.

The experimental protocol consisted in recording three main data during meat cutting tasks, and analysing their variation when some of the workstation design parameters were changing.

Then the motion was replayed in the AnyBody modeling system (AnyBody, Aalborg, Denmark) in order to obtain muscle forces generated during the motion. A trend comparison has been done, comparing recorded and computed muscle activations. Results showed that most of the computed activations were qualitatively close from the recorded ones (similar shapes and peaks), but quantitative comparison led to major differences between recorded and computed activations (the trend followed by the recorded activations in regard of a workstation design parameter, such as the table height, is not obtained with the computed activations) [15]. We currently explore those results to see if the fact that co-contraction of single joints muscles is badly estimated by classical inverse dynamics method can be a reason of this issue. We also work on the co-contraction simulation in order to improve the results.

This work has been done in collaboration with the Center for Sensory-motor Interaction (SMI, Aalborg University, Aalborg, Denmark), particularly Mark de Zee (Associate Professor) and Pascal Madeleine (Professor).

Furthermore, the fidelity of the VR simulator has to be evaluated. For example, a simulator for assembly task has been evaluated in comparing different types of interaction : real, virtual and virtual + force feedback. Objective and subjective metrics of discomfort led to highlight the influence of the environment on motor control and sensory feedback, changing more or less deeply the way the task is performed. The results particularly showed a distortion between the user's subjective rating of discomfort and the objective value associated to the postures they reached during the task execution. Nevertheless, scores obtained in real and virtual environments for objective and subjective indicators of discomfort were highly correlated [17], [16]. It indicates that despite the differences, the gap between real and virtual environments can be fulfilled. This work has been done within the frame of the european project FP7 VISIONAIR.

At last we proposed in collaboration with Thierry Duval (Hybrid team, Rennes) a new architecture for information sharing and bridging in collaborative virtual environments in application to ergonomics studies. This work has been awarded with a best paper award at The 4th IEEE conference on Cognitive Infocommunications (CogInfoCom 2013) [28].

6.3. Motion Sensing and analysis

Participant: Franck Multon [contact].

Sensing human activity is a very active field of research, with a wide range of applications ranging from entertainment and serious games to personal ambient living assistance, including rehabilitation. MimeTIC aims at proposing original methods to process raw motion capture data in order to compute relevant information according to the application.

In rehabilitation, we have collaborated with University of Montreal, Saint-Justine Hospital which main activity is rehabilitation of children with pathologies of the pyramidal control system. In this domain, defining metrics and relevant measurement to diagnose pathologies and to monitor patients during treatment is a key point. In gait, most of the previous works focus on gait spatio-temporal parameters (such as step length, frequency, stride duration, global speed) which could be measured with two main families of systems: 1) one-point measurement with a force plate, one accelerometer or dedicated devices (such as a Gait Ride), or 2) multi-point measurement systems with motion sensors or markers placed over the patient's skin. The former provides the clinician with compact but incomplete knowledge whereas the latter provides him with numerous data which are sometimes difficult to analyze and to get (specific technical skills are required). The first step to any type of analysis is to detect the main gait events, such as foot strikes and toe offs. In treadmill walking, widely used in rehabilitation as it enables the clinician to analyze numerous gait cycles in a limited place with a controlled speed, automatically detecting such gait events requires complex devices with specific technical skills (such as calibration and post-processing with motion capture systems).

Recent papers have demonstrated that low-cost and easy-to-use depth cameras (such as a Kinect from Microsoft) look promising for serious applications requiring motion capture. However there exist some confusion between the feet and the ground at foot strike and foot off leading to bad estimation of the gait cycle events. We have proposed an alternative approach that consists in using the strong correlation between knee and foot trajectories to deduce foot strikes thanks to knee movements. The extremes of the distance between the two knees along the longitudinal axis provides us with very accurate gait events detection compared to previous works.

A second contribution consisted in defining a global gait asymmetry index according to depth images provided by a Kinect. In previous works this index relied on computing ratio between joint angles. With a Kinect, joint angles may be very noisy that could affect the asymmetry index. We have introduced a new index which is directly deduced from depth images without any joint angle estimation nor skeleton fitting. The method consists in building a model of the gait cycle of the patient by averaging depth images recorded along several cycles. As a consequence the noise within the instantaneous depth images is filtered leading to accurate surfaces of the patient gait (leading to a 3D+time data structure). The main vertical axis of the surface is

used to define a symmetry plane. Consequently surfaces of the right part of the body can be symmetrized to be compared to the left part at compatible times in the gait cycle (such as a right foot strike is symmetrized to be compared to a left foot strike). The comparison between the two surfaces leads to a promising asymmetry index. The results (see Figure 4) demonstrate that this method is able to significantly distinguish asymmetrical gaits obtained by adding a 5cm sole under one of the feet of healthy subjects. Ongoing works consist in comparing this index to previously published ones which were based on accurate motion capture data. It will also be applied to unimpaired gaits of pathological subjects.

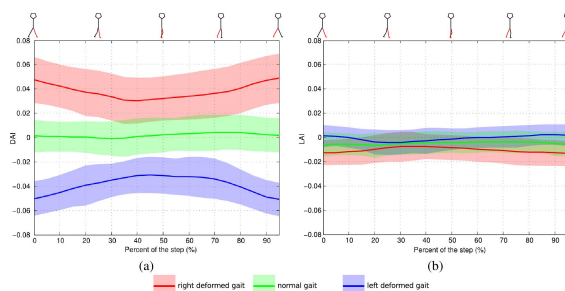


Figure 4. Longitudinal (DAI) and lateral (LAI) Asymmetry indexes computed thanks to depth images for normal gait and two artificial modification (adding a 5cm sole below the left or the right foot). The asymmetry index is computed all along the gait cycle and was able to statistically distinguish asymmetrical gaits.

6.4. VR and Sports

Participants: Richard Kulpa [contact], Benoit Bideau, Franck Multon.

Previous works in MimeTIC have shown the advantage of using VR to design and carry-out experiments on perception-action coupling in sports, especially for duels between two opponents. However the impact of using various technical solutions to carry-out this type of experiment in sports is not clear. Indeed immersion is performed by using interfaces to capture the motion/intention of the user and to deliver various multi-sensory feedbacks. These interfaces may affect the perception-action loop so that results obtained in VR cannot be systematically transferred to real practice.

Most of the applications in VR provide the user with visual feedbacks in which the avatar of the user can be more or less simplified (sometimes limited to a hand or the tools he his carrying). In first person view in caves the user generally does not need accurate avatars as he can perceive his real body but some authors have shown that the perception of distances is generally modified. Some authors have also demonstrated that first-person view was less efficient than third person view with avatars when performing accurate tasks such as reaching objects in constrained environments. We proposed an experiment to evaluate which type of feedback was the most appropriate one for complex precision tasks, such as basketball free-throw. In basketball free-throw the user has to throw a ball into a small basket placed at over 4.5m far from him. Thus perception of distance is actually a key point in such a task. Beginners and experts carried-out a first experiment in real in order to measure their motion and performance in real situation. Then beginners were asked to perform free throws with a real ball in hands, but in three conditions in a Cave (Immersia Room, Rennes): 1) first-person view (see Figure 5), 2) third-person view with the visual feedback of the ball's position, and 3) third-person view the virtual ball and additional rings modeling the perfect trajectory for the ball to get in the basket. Results show that significant difference exists in ball speed between first-person view condition compared to real condition whereas no difference exist in third-person view conditions. If we focus on successful throws only, ball speed in the last condition 3) was very similar to real condition whereas all the other VR conditions

(1) and 2)) lead to significant differences compared to real situation. In all VR conditions the height of ball release was significantly higher in VR compared to real situation. These results show that VR conditions lead to adaptations in the way people perform such a precision task, especially for ball speed and height of ball release. However this difference is significantly higher with first person view and tends to zero in condition 3). Future works will tend to evaluate new conditions with avatars and complementary points of view (such as lateral and frontal views together as suggested by some authors). It will also be important to more clearly understand the problem of perception of distances in such an environment. This work has been performed in cooperation with University of Brassov in Romania.



Figure 5. First-person view condition in the basket free-throw performed in a cave (Immersia Room, France).

Another key feedback is the external forces associated with the task. In most sports applications such forces are strongly linked to performance. However delivering these forces in virtual environments is still a challenge as it required haptic devices that could affect the way the users perform the task (with a different grip compared to real situation and limitations in dynamic response of the device). Pseudohaptics has been introduced in the early 2000. It consists in using visual feedbacks to make people perceive the forces linked to a task. However this approach has not been tested for whole-body interaction. In collaboration with Hybrid team in Inria Rennes, we studied how the visual animation of a self-avatar could be artificially modified in real-time in order to generate different haptic perceptions. In our experimental setup participants could watch their self-avatar in a virtual environment in mirror mode. They could map their gestures on the self-animated avatar in real-time using a Kinect. The experimental task consisted in a weight lifting with virtual dumbbells that participants could manipulate by means of a tangible stick. We introduce three kinds of modification of the visual animation of the self-avatar: 1) an amplification (or reduction) of the user motion (change in C/D ratio), 2) a change in the dynamic profile of the motion (temporal animation), or 3) a change in the posture of the avatar (angle of inclination). An example is depicted in Figure 6. Thus, to simulate the lifting of a "heavy" dumbbell, the avatar animation was distorted in real-time using: an amplification of the user motion, a slower dynamics, and a larger angle of inclination of the avatar. We evaluated the potential of each technique using an ordering task with four different virtual weights. Our results show that the ordering task could be well achieved with every technique. The C/D ratio-based technique was found the most efficient. But participants globally appreciated all the different visual effects, and best results could be observed in the combination configuration. Our results pave the way to the exploitation of such novel techniques in various VR applications such as for sport training, exercise games, or industrial training scenarios in single or collaborative mode.

6.5. Autonomous Virtual Humans

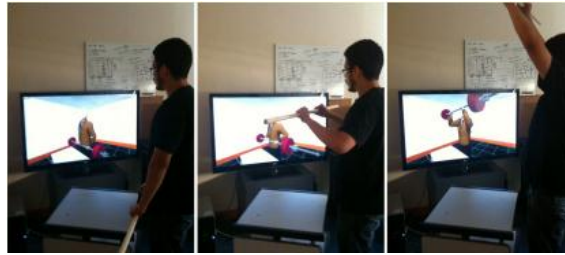


Figure 6. Weight discrimination task: the animation of the avatar showed a lifting effort according to the weight of the virtual dumbbell and the user has to rank the conditions from the lightest to the heaviest mass.

6.5.1. Space and Time Constrained Task Scheduling for Crowd Simulation

Participants: Carl-Johan Jorgensen, Fabrice Lamarche [contact].

Crowd distribution in cities highly depends on how people schedule their daily activities. When performing an intended activity, people decisions and behavior mainly consist in scheduling tasks that compose this activity, planning paths between locations where these tasks should be performed, navigating along the planned paths and performing the scheduled tasks.

We proposed a task scheduling model aims at selecting where, when and in which order several tasks, representing an intended activity, should be performed. The proposed model handles spatial and temporal constraints relating to the environment and to the agent itself. Personal preferences, characterizing the agent, are also taken into account. Produced task schedules are optimized on the long term and exhibit adequate choices of locations and times with respect to the agent intended activity and its environment. Once computed, these task schedules are relaxed and used to drive a microscopic crowd simulation in which observable flows of pedestrians emerge from the scheduled individual activities. Such simulations are easy to produce and do not require the use of a complex decisional model. In terms of validation, we conducted an experiment that shows that our algorithm produces task schedules which are representative of humans' ones.

This work is part of the iSpace&Time project in which virtual cities are populated with virtual pedestrians and vehicles.

6.5.2. Long term planning and opportunism

Participants: Philippe Rannou, Fabrice Lamarche [contact].

Autonomous virtual characters evolve in dynamic virtual environments in which changes may be unpredictable. One main problem when dealing with long term action planning in dynamic environment is that an agent should be able to behave properly and adapt its behavior to perceived changes while still fulfilling its goals.

We propose a system that combines long term action planning with failure anticipation and opportunism. The system is based on a modified version of an HTN planning algorithm. It generates plans enriched with information that enable a monitor to detect relevant changes of the environment. Once such changes are detected, a plan adaptation is triggered. Such adaptations include modifying the plan to react to a predicted failure and more importantly to exploit opportunities offered by the environment.

This system has been extended to better take into account the relationship between action planning and the environment. It is now combined with our space and time constrained tasks scheduling system (Cf. 6.5) to optimize the choice of locations where actions should be performed.

6.6. Interactive Virtual Cinematography

Participants: Marc Christie [contact], Christophe Lino, Cunka Sanokho.

The domain of Virtual Cinematography explores the operationalization of rules and conventions pertaining to camera placement, light placement and staging in virtual environments. Within the context of the ANR CHROME project, we have tackled the problem of portraying events in complex crowd simulations using steering behaviors. The system we proposed relies on Reynolds' model of steering behaviors to control and locally coordinate a collection of camera agents similar to a group of reporters. In our approach, cameras are either in a scouting mode, searching for relevant events to convey, or in a tracking mode following one or more unfolding events. The key benefit, in addition to the simplicity of the steering rules, holds in the capacity of the system to adapt to the evolving complexity of crowd simulations by self-organizing the cameras to track most of the events. The results have been presented at the Motion in Games conference [21].

We have also created a table-top interactive application to offer collaborative and high-level control on multi-dimensional and temporal data. This has been applied to the collaborative control of cinematographic parameters in a virtual movie, using our cinematographic engine [26].

In the ANR project Cinecitta, we have proposed means to evaluate the sense of balance in synthetic shots. Balance represents the equilibrium of visual weights in the screen, *i.e.* equilibrium of the visual interests one perceives. Balance is a key criteria in the aesthetics of a shot, and only a few approaches have seriously tackled this issue. In our approach, we rely on a dataset of well-balanced shot extracted from real movies to construct a balance feature space. The balance feature space is then used to estimate the sense of balance in new synthetic shot. We have furthermore extended the approach by automatically recomputing viewpoints to improve balance. A journal paper is under submission in Computer Graphics Forum.

6.7. Interactive Storytelling

Participants: Marc Christie [contact], Hui-Yin Wu.

In 2013, within the Inria Associate Team FORMOSA (see 8.3.1.1), we have proposed a framework for the creation of parametrable and personalized stories in interactive storytelling. In any kind of storytelling, the success of the story relies both on the intricate plot design and control of the author as well as the emotional feedback of the user. With the assistance of computing algorithms combined with the maturing understanding of narrative structures, it is possible for interactive stories to create a more personalized, engaging, and well-controlled narrative content to users than traditional linear narrative. And with the emergence of new storytelling technologies, critical issues concern the creation of such complex narratives in virtual 3D environments, and the coherent simulation of these interactive narratives.

In the framework we proposed, the author can specify characteristics on the story structure and fragments (pieces of story) in order to generate variations of interactive stories. The characteristics we consider are genre, story complexity, and Chatman's modes of plot (eg a good hero fails). The story generation model we devised combines a branching story structure with a three-step graph traversal algorithm that filters and recombines story fragments from the characteristics, generating a high-level interactive script that satisfies all authorial constraints, and provides sufficient abstraction from the technical implementation. The script is then simulated in a real-time storytelling system, featuring autonomous characters and automatic camera control. The work has been presented as a short paper in the CASA conference [30].

We then extended this approach to handle temporal aspects of discourse in stories (*i.e.* how to temporally rearrange fragments of a story while maintaining consistency and logic whatever the user's choices). By rewriting our graph traversal algorithm (which filters inconsistent branches, and propagates constraints along the branches), and performing the graph traversal on each choice selected by the user, we enable the simulation of consistent temporal variations in stories. This typically allows the creation of flashbacks, flashforwards, parallel and embedded stories. Early results have been presented as a poster at Motion in Games 2013 [21].

6.8. Haptic Cinematography

Participant: Marc Christie [contact].

In 2013, we have demonstrated an approach to Haptic Cinematography in very selective events (2013 CHI conference [40], 2013 Siggraph Emerging Technology [41], 2013 UIST conference [39]). This is joint work with members of the Hybrid team (Anatole Lécuyer, Fabien Danieau) and members of the Technicolor Company (Philippe Guillotel, Nicolas Mollet, Julien Fleureau). Haptic cinematography consists in enhancing our audio-visual experience of movies by adding haptic effects related to the semantics of camera motions. Camera motions in movies, which are typically non-diegetic elements in a narrative, tend to enhance user experience both visually and emotionally. The questions we address here are (i) whether the coupling between camera motions and haptic motions improve this experiences and (ii) what are the rules and recommendations for coupling these motions. Results, that we published in the IEEE Multimedia journal [8], demonstrate that (i) the coupling is effective when precisely synchronized, (ii) the direction of motions between the camera and the haptic motions do not need to be correlated, and (iii) haptic metaphores can easily be perceived by the spectators. This opens great perspectives as to how haptic devices can enhance audio-visual contents in more subtle ways than straightforward mappings between diegetic elements and haptic motions.

6.9. Biomechanics for avatar animation

Participants: Julien Pettré [contact], Charles Pontonnier, Georges Dumont, Franck Multon, Ana Lucia Cruz Ruiz, Steve Tonneau.

Bio-inspired controllers and planners are compelling for avatar animation. We are currently engaging several works on the subject within the frame of the ENTRACTE project 8.1.5.

Ana-Lucia Cruz-Ruiz has been recruited as a PhD student since november 2013 to begin to work on musculoskeletal-based methods for avatar animation. More precisely, the goal of this thesis is to define and evaluate a modular and multiscale whole-body musculoskeletal model usable to analyze and human movement and synthesize realistic avatar animations. The specificity of the subject is hidden in the words “modular” and “multiscale”. “Modular” says that the model has to be easily tunable to be modified in accordance with the investigated motor control theories (uncontrolled manifold, motor synergies,...). “Multiscale” means that the model has to exhibit multiple levels of details cohabiting at the same time, depending on the region of interest investigated. At last, the model have to be easily scalable, in order to be applied to different morphologies. Moreover, she currently explores musculoskeletal-based simplified joint behaviors to improve torque-based dynamics applications.

We also address the problem of planning human motion in constrained environment. In previous approach, planning human motion is performed based on robotics planning algorithms the objective of which is to avoid obstacles. In our approach, we suggest that creating contacts with the obstacles of the environment is actually a mean to perform a motion tasks. We thus model human motion as a sequence of contacts between humans and obstacles. A contact planner is being developed, and results being prepared for publication.

6.10. Crowds

Participants: Julien Pettré [contact], Anne-Hélène Olivier, Julien Bruneau, Jonathan Perrinet, Kevin Jordao, David Wolinski.

6.10.1. Analysis of Locomotion Trajectories during Collision Avoidance

The experimental observation of physical interactions between real walkers is for us a great source of inspiration for the design of realistic microscopic models of crowd simulation. This year, we have continued analysing locomotion trajectories of real walkers during collision avoidance tasks. Analysis focused on individual strategies and role set to solve such a reciprocal interaction. Our analysis revealed that walkers combine re-orientation and speed adaptations to avoid collisions, but more importantly, that the strategies, as well as the global amount of adaptations is dependent on the role each one has in the avoidance (e.g., passing first, giving way). Our results are reported in [13]. In addition, we inspected the role of psychological factors on the metrics of interactions [27].

6.10.2. Evaluation of Locomotion Trajectories performed in Virtual Reality

Virtual Reality rooms are physically limited in space, and prevent users virtually walking by really walking in larger virtual spaces: a locomotion interface is employed to overcome this issue. The interface is composed of a peripheral device, such as joystick, as well as of a software component which transform users' actions on the peripheral device into a virtual locomotion. In this work, we wondered if users were performing similar trajectories in virtual than in vivo: such question is important when aiming at using VR for motion analysis purpose. We evaluated the bias introduced by several couples of devices and software components during the execution of goal directed locomotion tasks. As reported in [7], impressive similarities on the formed trajectories even when the device control motions are radically different in comparison with walking motions.

6.10.3. Virtual Populations for large-scale digital environments and Cultural Heritage Applications

We are developing techniques dedicated to the animation of large virtual populations at very low computational cost based on the crowd patches techniques. Crowd patches can be described as 3D animated textures that small groups animations. They are composed in space to form large population. This year, we coupled the crowd patches approach with mutable shape models: such association enable users designing patches composition in an interactive manner, as introduced in [22]. We applied those techniques to design populations of some old Malaysian trading ports [25].

6.10.4. Macroscopic derivations of microscopic simulation models

Crowd phenomenon exhibit macroscopic structures which derive from the combination of local interactions between individuals. Together with the IMT in Toulouse in the frame of the ANR-Pedigree project (term. 2012), the microscopic models developed in our team has been derived into macroscopic models to demonstrate their ability to provoke the emergence of some typical macroscopic structures [35], [36].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Grants with Industry

7.1.1. Cifre Contract with Faurecia

Participants: Franck Multon [contact], Pierre Plantard.

This contract aims at developing new ergonomics assessments based on inaccurate Kinect measurements in manufactures on real workers. The main challenges are:

- being able to improve the Microsoft Kinect measurement in order to extract accurate poses from depth images while occlusions may occur,
- developing new inverse dynamics methods based on such inaccurate kinematic data in order to estimate the joint torques required to perform the observed task,
- and proposing a new assessment tool to translate joint torques and poses into potential musculoskeletal disorders risks.

Faurecia has developed its own assessment tool but it requires tedious and subjective tasks for the user, at specific times in the work cycle. By using Kinect information we aim at providing more objective data over the whole cycle not only for specific times. We also wish to make the user focus on the interpretation and understanding of the operator's tasks instead of taking time estimating joint angles in images.

This work is performed in close collaboration with an ergonomist in Faurecia together with the software development service of the company to design the new version of their assessment tool. This tool will be first evaluated on a selection of manufacture sites and will then be spread worldwide among the 270 Faurecia sites in 33 countries.

This contract enabled us to hire Pierre Plantard as a PhD student to carry-out this work in MimeTIC and M2S Lab. He started in January 2013 and will finish in December 2015.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR Contint: *iSpace&Time*

Participants: Fabrice Lamarche [contact], Julien Pettré, Marc Christie, Carl-Johan Jorgensen.

The *iSpace&Time* project is founded by the ANR and gathers six partners: IGN, Lamea, University of Rennes 1, LICIT (IFSTTAR), Telecom ParisTech and the SENSE laboratory (Orange). The goal of this project is the establishment of a demonstrator of a 4D Geographic Information System of the city on the web. This portal will integrate technologies such as web2.0, sensor networks, immersive visualization, animation and simulation. It will provide solutions ranging from simple 4D city visualization to tools for urban development. Main aspects of this project are:

- Creation of an immersive visualization based on panoramic acquired by a scanning vehicle using hybrid scanning (laser and image).
- Fusion of heterogeneous data issued by a network of sensor enabling to measure flows of pedestrians, vehicles and other mobile objects.
- Use of video cameras to measure, in real time, flows of pedestrians and vehicles.
- Study of the impact of a urban development on mobility by simulating vehicles and pedestrians.
- Integration of temporal information into the information system for visualization, data mining and simulation purpose.
- The mimetic team is involved in the pedestrian simulation part of this project. This project started in 2011 and will end in 2014.

8.1.2. ANR Contint: *Chrome*

Participants: Julien Pettré [contact], Kevin Jordao, Oriane Siret.

The *Chrome* project is leaded by Julien Pettré, member of MimeTIC. Partners are: Inria-Grenoble IMAGINE team (Remi Ronfard), Golaem SAS (Stephane Donikian), and Archivideo (Francois Gruson). The project has been launched in september 2012.

The *Chrome* project develops new and original techniques to massively populate huge environments. The key idea is to base our approach on the crowd patch paradigm that enables populating environments from sets of pre-computed portions of crowd animation. These portions undergo specific conditions to be assembled into large scenes. The question of visual exploration of these complex scenes is also raised in the project. We develop original camera control techniques to explore the most relevant part of the animations without suffering occlusions due to the constantly moving content. A far term goal of the project is to enable populating a large digital mockup of the whole France (Territoire 3D, provided by Archivideo). Dedicated efficient Human animation techniques are required (Golaem). A strong originality of the project is to address the problem a crowded scene visualisation through the scope of virtual camera control (Inria Rennes and Grenoble)

8.1.3. ANR TecSan: *RePLiCA*

Participant: Armel Crétual [contact].

The goal of *RePLiCA* project is to build and test a new rehabilitation program for facial praxia in children with cerebral palsy using an interactive device. *RePLiCA* started in january 2012 and will end in July 2015.

In a classical rehabilitation program, the child tries to reproduce the motion of his/her therapist. The feedback he/she has lays on the comparison of different modalities: the gesture of the therapist he/she has seen few seconds ago (visual space) and his/her own motion (proprioceptive space). Unfortunately, besides motor troubles these children often have some cognitive troubles and among them a difficulty to convert the information from a mental space to another one.

The principle of our tool is that during a rehabilitation session the child will observe simultaneously on the same screen an avatar, the virtual therapist's one, performing the gesture to be done, and a second avatar animated from the motion he actually performs. To avoid the use of a too complex motion capture system, the child will be filmed by a simple video camera. One first challenge is thus to be able to capture the child's facial motion with enough accuracy. A second one is to be able to provide him/her an additional feedback upon the gesture quality comparing it to a database of healthy children of the same age.

8.1.4. ANR JCJC: *Cinecitta*

Participants: Marc Christie [contact], Cunka Sanokho.

Cinecitta is a 3-year young researcher project funded by the French Research Agency (ANR) lead by Marc Christie. The project started in October 2012 and will end in October 2015.

The main objective of Cinecitta is to propose and evaluate a novel workflow which mixes user interaction using motion-tracked cameras and automated computation aspects for interactive virtual cinematography that will better support user creativity. We propose a novel cinematographic workflow that features a dynamic collaboration of a creative human filmmaker with an automated virtual camera planner. We expect the process to enhance the filmmaker's creative potential by enabling very rapid exploration of a wide range of viewpoint suggestions. The process has the potential to enhance the quality and utility of the automated planner's suggestions by adapting and reacting to the creative choices made by the filmmaker. This requires three advances in the field. First, the ability to generate relevant viewpoint suggestions following classical cinematic conventions. The formalization of these conventions in a computationally efficient and expressive model is a challenging task in order to select and propose the user with a relevant subset of viewpoints among millions of possibilities. Second, the ability to analyze data from real movies in order to formalize some elements of cinematographic style and genre. Third, the integration of motion-tracked cameras in the workflow. Motion-tracked cameras represent a great potential for cinematographic content creation. However given that tracking spaces are of limited size, there is a need to provide novel interaction metaphors to ease the process of content creation with tracked cameras. Finally we will gather feedback on our prototype by involving professionals (during dedicated workshops) and will perform user evaluations with students from cinema schools.

8.1.5. ANR Contint: *ENTRACTE*

Participants: Charles Pontonnier [contact], Georges Dumont, Nicolas Bideau, Franck Multon, Julien Pettré, Richard Kulpa, Ana Lucia Cruz Ruiz, Steve Tonneau.

The ANR project ENTRACTE is a collaboration between the Gepetto team in LAAS, Toulouse (head of the project) and the Inria/MimeTIC team. The project started in November 2013 and will end in August 2017. The purpose of the ENTRACTE project is to address the action planning problem, crucial for robots as well as for virtual human avatars, in analyzing human motion at a biomechanical level and in defining from this analysis bio-inspired motor control laws and bio-inspired paradigms for action planning. The project is launched since november 2013 and Ana-Lucia Cruz-Ruiz has been recruited as a PhD student since this date to begin to work on musculoskeletal-based methods for avatar animation. Moreover, Steve Tonneau, a PhD student currently entering in its third year is also developing bio-inspired posture generators for avatar navigation in encumbered environments.

8.1.6. ADT: *Man-IP*

Participant: Franck Multon [contact].

The ADT-MAN-IP aims at proposing a common production pipeline for both MimeTIC and Hybrid teams. This pipeline intends to facilitate the production of populated virtual reality environments.

The pipeline starts with the motion capture of an actor, using motion capture devices such as a Vicon (product of Oxford Metrics) system. To do so, we need to design new methods to automatically adapt all motion captures data to an internal skeleton that can be reused to retarget the motion to various types of skeletons and characters. The purpose is then to play this motion capture data on any type of virtual characters used in the demos, regardless their individual skeletons and morphology. The key point here is to make this process be as automatic as possible.

The second step in the pipeline is to design a high level scenario framework to describe a virtual scene and the possible user's interactions with this scene so that he/she can interact with the story directly.

In this ADT we also will have to connect these two opposite parts into a unique framework that can be used by non-experts in computer animation to design new immersive experiments involving autonomous virtual humans. The resulting framework could consequently be used in the Immersia immersive room for various types of application.

8.2. European Initiatives

8.2.1. FP7 Projects

8.2.1.1. INFRA-FP7: VISIONAIR

Participants: Georges Dumont [contact], Charles Pontonnier.

Acronym: VISIONAIR

Title: VISION Advanced Infrastructure for Research

Duration: 2011-2015

See also: <http://www.infra-visionair.eu/>

The european project VISIONAIR began in February 2011 in the infrastructure call of FP7. The project's goal is to create a European infrastructure that should be a unique, visible and attractive entry towards high level visualization facilities. These facilities will be open to the access of a wide set of research communities. By integrating our existing facilities, we will create a world-class research infrastructure enabling to conduct frontier research. This integration will provide a significant attractiveness and visibility of the European Research Area. The partners of this project have proposed to build a common infrastructure that would grant access to high level visualization and interaction facilities and resources to researchers. Indeed, researchers from Europe and from around the world will be welcome to carry out research projects using the visualization facilities provided by the infrastructure. Visibility and attractiveness will be increased by the invitation of external projects.

This project is built with the participation of 26 European partners.

Our actual Virtual Reality systems allowed us to be a key partner within this European project. Our Immersia (<http://www.irisa.fr/immersia>) Virtual Reality room is, in Europe, a key place for virtual reality. We are leading the Work Package 9 on Advanced methods for interaction and collaboration of this project and are deeply involved in the directory board and in the scientific piloting committee.

Within the frame of this project, studies on VR and sports about basketball throwing (see 6.4) and VR and ergonomics about fidelity of virtual environments for ergonomic applications (see 6.2) have been leaded.

8.3. International Initiatives

8.3.1. Inria Associate Teams

8.3.1.1. FORMOSA

Title: Fostering Research on Models for Storytelling Applications

Inria principal investigator: Marc Christie

Partner contact: Pr. Tsai Yen li

International Partner (Institution - Laboratory - Researcher):

National Cheng Chi University (Taiwan) - Intelligent Media Lab - Marc Christie

Duration: 2013 - 2015

See also: <http://www.irisa.fr/mimetic/GENS/mchristi/EA-FORMOSA/>

The application context targeted by this proposal is Interactive Virtual Storytelling. The growing importance of this form of media reveals the necessity to re-think and re-assess the way narratives are traditionally structured and authored. In turn, this requires from the research community to address complex scientific and technical challenges at the intersection of literature, robotics, artificial intelligence, and computer graphics. This joint collaboration addresses three key issues in virtual storytelling: (i) delivering better authoring tools for designing interactive narratives based on literary-founded narrative structures, (ii) establishing a bridge between the semantic level of the narrative and the geometric level of the final environment to enable the simulation of complex and realistic interactive scenarios in 3D, and (iii) providing a full integration of the cinematographic dimension through the control of high-level elements of filmic style (pacing, preferred viewpoints, camera motion). The project is founded on a past solid collaboration and will rely on the team's complementarity to achieve the tasks through the development of a joint research prototype.

8.3.1.2. SIMS

Title: Toward realistic and efficient simulation of highly complex systems

Inria principal investigator: Julien Pettré

Partner contact: Pr. Ming Lin

International Partner (Institution - Laboratory - Researcher):

University of North Carolina at Chapel Hill (United States) - GAMMA Research Group -
Julien Pettré

Duration: 2012 - 2014

See also: <http://www.irisa.fr/mimetic/GENS/jpettre/>

The general goal of SIMS is to make significant progress toward realistic and efficient simulation of highly complex systems which raise combinatory explosive problems. This proposal is focused on human motion and interaction, and covers 3 active topics with wide application range: 1. Crowd simulation: virtual human interacting with other virtual humans, 2. Autonomous virtual humans: who interact with their environment, 3. Physical Simulation: real humans interacting with virtual environments. SIMS is orthogonally structured by transversal questions: the evaluation of the level of realism reached by a simulation (which is a problem by itself in the considered topics), considering complex systems at various scales (micro, meso and macroscopic ones), and facing combinatory explosion of simulation algorithms.

8.4. International Research Visitors

8.4.1. Internships

- Alexandra Covaci, PhD student from University Brasso (Romania) partially funded by the VISION-AIR project and Brasso University, from March to April 2013. Joint works about virtual training in sports applied to basketball free throw.

9. Dissemination

9.1. Scientific Animation

- F. Multon: **Reviewer** for Journal of Biomechanics, IEEE Transaction of Affective Computing, PlosOne, Computer Methods in Biomedical Engineering journal, Computer & Graphics journal, IEEE TVCG journal, Computer Animation and Virtual Worlds journal **Program Committee member** of ACM SIGGRAPH Asia (Sketches and posters), Motion in Games Conference MIG2013, CASA 2013, **Scientific expert** for "Pole Productique de Bretagne", and Auteo association, in ergonomics, **Session chairman** of in Motion in Games 2013, **Associate Editor** of the Presence journal MIT Press since 2012, **Steering committee member** of Motion in Games Conference, **reviewer** for national ANR projects in computer sciences and health domains, for the Belgium FNRS foundation, and for the HongKong Baptist University for internal promotions.
- M. Christie: **Reviewer** for IEEE Transactions on Visualization and Computer Graphics, ACM Transactions on Graphics, The Visual Computer, Computer Graphics Forum, Computers and Graphics, Journal on Computing and Cultural Heritage, Foundations on Digital Games, Pervasive Computing, Eurographics, Computer And Graphics, Grapp, Motion in Games, Computer Animation and Social Agents **Senior Program Committee member** of Foundations on Digital Games, **Program Committee member** of Grapp, Smartgraphics, **Steering Committee** of Smartgraphics, **External scientific expert** for Natural Sciences and Engineering Research Council of Canada (Discovery Grants)
- R. Kulpa: **Reviewer** for Eurographics, Computer Graphics Forum, GRAPP, Journal of Graphics Tools, Journal of Sport Science, Pacific Graphics, PlosOne, Siggraph Asia, Transaction on Visualization and Computer Graphics, IEEE VR; **Associate Editor** of the Presence journal MIT Press since 2012; **Leader** of a European Intensive Program called "Routine & Cutting-edge Technologies in Physical Activity: Implication for Health & Sport Performance" with the Queen's University of Belfast and the Universitat de Valencia.
- F. Lamarche: **Reviewer** for Computer Animation and Virtual Worlds
- C. Pontonnier: **Reviewer** for IEEE Transactions on Visualization and Computer Graphics, International Journal of Virtual Reality, **Scientific expert** for ANR.
- J. Pettré: **Reviewer** for ACM Transactions on Graphics, Siggraph, Siggraph Asia, Eurographics, Pacific Graphics, Computer Animation and Social Agents, ACM/Eurographics Symposium on Computer Animation, IEEE Transactions on Visualization and Computer Graphics, Computer Animation and Virtual Worlds, ICRA, VR, Journal of Computational Science, Computer Graphics Forum, Autonomous Robots, Motion in Game Conference, **Program Committee member** of Pacific Graphics, Symposium on Computer Animation, International Conference on Computer Graphics Theory and Applications **Scientific expert** for ANR.
- A. Créteil: **Reviewer** for Medical & Biological Engineering & Computing, Journal of Electromyography and Kinesiology, Journal of Musculoskeletal & Neuronal Interactions, Computer Methods in Biomechanics & Biomedical Engineering, **Editorial Board** of Journal of Electromyography and Kinesiology, **Scientific expert** for ANR TecSan program, PCCA (Romanian equivalent of French ANR).
- G. Dumont: **Head** of Media and Interaction department of IRISA (UMR 6074), **Member** of the Selection Committee (CSV) of the Competitiveness Cluster "Media and Networks" (<http://www.images-et-reseaux.com/>), **Member** of Executive Board of international Journal IJIDeM. **Reviewer** for ASME-IMECE2013, ASME-DETC2013, IEEE Transactions on Visualization and Computer Graphics.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- Georges Dumont
 - First year of Mechatronics : Design project, 24h, École Normale Supérieure de Rennes, France

Master2, Mechatronics : Mechanical simulation in Virtual reality, 36h, level M2, Rennes 1 University and École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : Mechanics of deformable systems, 40h, level M2, École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : oral preparation to agregation competitive exam, 20h, level M2, École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : Vibrations in Mechanics, 10h, level M2, École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : Multibody Dynamics, 9h, level M2, École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : Finite Element method, 12h, level M2, École Normale Supérieure de Rennes, France

Master2, Mechatronics : Responsible of the second year of the master, Rennes 1 University and École Normale Supérieure de Rennes, France

- Charles Pontonnier

ESM2 majeure mécanique (Master 1 level) : Numerical techniques, 40h, École Spéciale Militaire de Saint-Cyr Coëtquidan, France

ESM2 majeure mécanique (Master 1 level) : Numerical simulation of mechanical systems, 28h, École Spéciale Militaire de Saint-Cyr Coëtquidan, France

ESM2 majeure mécanique (Master 1 level) : Vibrations in Mechanics, 24h, École Spéciale Militaire de Saint-Cyr Coëtquidan, France

ESM2 majeure électronique (Master 1 level) : Modelisation and control of manipulators and mobile robots, 40h, École Spéciale Militaire de Saint-Cyr Coëtquidan, France

EMIA 1 majeure électronique (Bachelor level) : numerical control, 40h, École Inter-Armes de Saint-Cyr Coëtquidan, France

Master2, formation des enseignants du supérieur : Numerical tools for reasearch, 10h, level M2, École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : Design, simulation and control of mechanical systems, 16h, level M2, École Normale Supérieure de Rennes, France

Master2, formation des enseignants du supérieur : Practicals: identification and control of mechanical systems, 24h, level M2, École Normale Supérieure de Rennes, France

- Franck Multon

"Image et Mouvement - IMO" (Master 2 Level): leader of the module, Master M2RI Research in Computer Sciences, INSA Rennes, France

"Santé et performance au travail : études de cas" (Master 1 Level): leader of the module, Master M2S Sports Sciences, University Rennes2, France

"Analyse biomécanique de la performance motrice" (Master 1 Level): leader of the module, Master M2S Sports Sciences, University Rennes2, France

"Modélisation et simulation du mouvement" (Master 2 Level): Leader of the module, Master M2S, Sports Sciences, University Rennes2, France

"Ergonomie du poste de travail" (Licence 2-3 levels): Licence STAPS, Ergonomics and sports sciences, University Rennes2, France

"Facteurs psycho sociaux et ergonomie" (Master 2 Level): Mastère Excellence opérationnelle, INSA Rennes, France

- Richard Kulpa

Co-leader of the Master M2S, Sports Sciences and Health, University Rennes2, France

"Outils informatiques d'analyse des données" (Master 2 Level): Leader of the module, Master M2S, Sports Sciences and Health, University Rennes2, France

DIU "Sciences du Mouvement Humain": leader of the module "Nouvelles technologies", University Rennes2, France

"Biomécanique" (Licence 2-3 levels): Licence STAPS, Ergonomics and sports sciences, University Rennes2, France

"Méthodes numériques d'analyse du mouvement" (Licence 2-3 levels): Licence STAPS, Ergonomics and sports sciences, University Rennes2, France

"De la capture de mouvements à l'animation d'humain virtuel" (Engineering school): Ecole Centrale de Nantes, France

"L'animation d'humain virtuel": IUT Bordeaux 1, France

- Armel Créteil
 - Responsible for Master 1 Level of Master "Mouvement, Sport, Santé" (M2S), University Rennes 2
 - "Méthodologie", leader of the module, Master M2S, University Rennes2, France
 - "Biostatistiques", leader of the module, Master M2S, University Rennes2, France
 - "Analyse cinématique du mouvement", Licence 1, University Rennes 2, France
- Marc Christie
 - "Multimedia Mobile" (Master 2 Level): leader of the module, Computer Science, University of Rennes 1, France
 - "Système d'information Tactiques" (Master 2 Level): Computer Science, University of Rennes 1, France
 - "Programmation Impérative 1" (Licence 1 level): leader of the module, University of Rennes 1, France

9.2.2. Supervision

- Christophe Lino
 - PhD** "Dynamic Spatial Partitions for Virtual Camera Control", University of Rennes1, defended in October 2013
 - Co-supervised** by Marc Christie and Kadi Bouatouch
- Pierre Plantard
 - PhD** "Maitriser les Troubles MusculoSquelettiques sur les postes de travail: apport de la simulation d'humains virtuels", University Rennes2, Cifre contract with Faurecia (2013-2015).
 - Supervised** by Franck Multon
- Steve Tonneau
 - PhD** "Synthèse et planification de mouvements pour des humains virtuels autonomes dans des environnements contraints", INSA Rennes (2011-2014)
 - Co-supervised** by Julien Pettré and Franck Multon
- Philippe Rannou
 - PhD** "Modèle rationnel pour les humains virtuels autonomes", University of Rennes 1 (2010-2014)
 - Co-supervised** by Fabrice Lamarche and Marie Odile Cordier
- Carl-Johan Jorgensen

PhD "Peuplement automatisé d'environnements urbains pour l'étude et la validation d'aménagements.", University of Rennes 1 (2011-2014)

Co-supervised by Fabrice Lamarche and Kadi Bouatouch

- Antoine Marin

PhD "Génération de trajectoires de marche par fonction de tâche", University of Rennes 2,(2010-2014)

Supervised by Armel Cretual
- Camille Pouliquen

PhD "Optimisation de modèles musculo-squelettiques au cours du geste sportif. Application au cyclisme et au handball", (2013-2016)

Co-supervised by Nicolas Bideau and Paul Delamarche
- Ana-Lucia Cruz-Ruiz

PhD "Design and evaluation of a modular and multiscale musculoskeletal model as a support to motion analysis-synthesis in computer animation and robotics", (2013-2016)

Co-supervised by Charles Pontonnier and Georges Dumont
- Jonathan Perrinet

PhD "Effet des émotions sur les interactions physique durant la marche", University Rennes1, funded by FP7 TANGO project (2010-2013).

Co-supervised by Julien Pettré and Stéphane Donikian
- David Wolinski

PhD "Modèles de simulation foules microscopiques réalistes", University Rennes1, funded by MRT (2012-2015).

Co-supervised by Julien Pettré and Stéphane Donikian
- Kevin Jordao

PhD"Peuplement massif de maquettes numériques immenses", University Rennes1, funded by the ANR-CHROME contract (2012-2015).

Supervised by Julien Pettré
- Julien Bruneau

PhD"Foules immersives", University Rennes1, funded by MRT (2013-2016).

Supervised by Julien Pettré

9.2.3. *Juries*

- Franck Multon

reviewer of Julien Lardy's PhD defense "Analyse et simulation cinématique du mouvement du bras lors de la manipulation d'un objet pour la simulation ergonomique à l'aide d'un mannequin numérique", IFSTTAR Lyon, University Lyon1, February 2013

reviewer of Zohrhe Anvari's PhD defense "Transport des enfants et locomotion : approche intégrative biomécanique et comparative chez l'humain et le primate non humain", Museum National d'Histoire Naturelle, September 2013

president of Thibaut Le Naour's PhD defense "Utilisation des relations spatiales pour l'analyse et l'édition de mouvement", University Bretagne Sud, December 2013

reviewer of Maud Pasquier's Phd defense "Segmentation de la locomotion humaine dans le domaine du sport et de la déficience à partir de capteurs embarqués", Université de Grenoble, September 2013

reviewer of Aurore Huchez's PhD defense "Etude de la gestion et du contrôle de l'inertie lors de la réalisation d'une tâche acrobatique complexe en gymnastique", Université de Valenciennes, January 2013

reviewer of Fabrice Megrot's HDR defense "Sur l'instabilité motrice: De l'équilibre du sujet à la marche du patient", Université Technologique de Compiègne, July 2013

president of Nicolas Courty's HDR defense "Contributions to Analysis/Synthesis Schemes in Computer Animation", Université Bretagne Sud, April 2013

- Armel Cretual

reviewer of Jessica Schiro's PhD defense "Analyse biomécanique multi variables du geste de tourner le volant chez les conducteurs sans déficiences motrices", Université de Valenciennes, March 2013

- Julien Pettré

reviewer of Panayiotis Charalambous's PhD defense "Data driven techniques for crowd simulation and evaluation", University of Cyprus, December 2013

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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- [2] C. LINO. , *Contrôle de caméra virtuelle à base de partitions spatiales dynamiques*, Université Rennes 1, October 2013, <http://hal.inria.fr/tel-00916128>
- [3] J. PERRINET. , *Évaluation de l'impact des facteurs émotionnels lors d'interactions physiques entre humains réels et virtuels*, Université Rennes 1 and Université Rennes 1, December 2013, <http://hal.inria.fr/tel-00938469>

Articles in International Peer-Reviewed Journals

- [4] K. BERVET, M. BESSETTE, L. GODET, A. CRÉTUAL. *KeR-EGI, a new index of gait quantification based on electromyography*, in "Journal of Electro - myography and Kinesiology", August 2013, vol. 23, n^o 4, pp. 930-7 [DOI : 10.1016/J.JELEKIN.2013.02.006], <http://hal.inria.fr/hal-00920716>
- [5] M. CAROLINE, B. BIDEAU, M. ROPARS, P. DELAMARCHE, R. KULPA. *Upper limb joint kinetic analysis during tennis serve: assessment of competitive level on efficiency and injury risks*, in "Scandinavian Journal of Medicine and Science in Sports", 2013, vol. 7 [DOI : 10.1111/SMS.12043], <http://hal.inria.fr/hal-00763596>
- [6] M. CAROLINE, R. KULPA, M. ROPARS, P. DELAMARCHE, B. BIDEAU. *Identification of Temporal Pathomechanical Factors during the Tennis Serve*, in "Medicine & Science in Sports & exercise", 2013 [DOI : 10.1249/MSS.0B013E318299AE3B], <http://hal.inria.fr/hal-00921445>
- [7] G. CIRIO, A.-H. OLIVIER, M. MARCHAL, J. PETTRÉ. *Kinematic Evaluation of Virtual Walking Trajectories*, in "IEEE Transactions on Visualization and Computer Graphics", 2013, vol. 19, pp. 671-680 [DOI : 10.1109/TVCG.2013.34], <http://hal.inria.fr/hal-00840160>

- [8] F. DANIEAU, J. FLEUREAU, P. GUILLOTTEL, N. MOLLET, M. CHRISTIE, A. LÉCUYER. *Toward Haptic Cinematography: Enhancing Movie Experience with Haptic Effects based on Cinematographic Camera Motions*, in "IEEE MultiMedia", January 2014, <http://hal.inria.fr/hal-00918074>
- [9] F. DANIEAU, A. LÉCUYER, P. GUILLOTTEL, J. FLEUREAU, N. MOLLET, M. CHRISTIE. *Enhancing audio-visual experience with haptic feedback: a survey on HAV*, in "IEEE Transactions on Haptics", January 2013, vol. 6, n^o 2, pp. 193-205, <http://hal.inria.fr/hal-00766259>
- [10] T. DUVAL, T. T. H. NGUYEN, C. FLEURY, A. CHAUFFAUT, G. DUMONT, V. GOURANTON. *Improving Awareness for 3D Virtual Collaboration by Embedding the Features of Users' Physical Environments and by Augmenting Interaction Tools with Cognitive Feedback Cues*, in "Journal on Multimodal User Interfaces", November 2013, <http://hal.inria.fr/hal-00908402>
- [11] L. GLONDU, S. C. SCHVARTZMAN, M. MARCHAL, G. DUMONT, M. A. OTADUY. *Fast Collision Detection for Fracturing Rigid Bodies*, in "IEEE Transactions on Visualization and Computer Graphics", January 2014, vol. 20, n^o 1, pp. 30-41 [DOI : 10.1109/TVCG.2013.98], <http://hal.inria.fr/hal-00874560>
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ligence", September 2013, vol. 27, n^o 8, 19 p. [DOI : 10.1142/S0218001413500237], <http://hal.inria.fr/hal-00857204>

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International Conferences with Proceedings

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- [22] K. JORDAO, J. PETTRÉ, M.-P. CANI. *Interactive techniques for populating large virtual cities*, in "Eurographics Workshop on Urban Data Modelling and Visualisation", Girona, Spain, Eurographics, May 2013, pp. 41-42 [DOI : 10.2312/UDMV/UDMV13/041-042], <http://hal.inria.fr/hal-00815691>

- [23] C.-J. JORGENSEN, F. LAMARCHE. *Combining Activity Scheduling and Path Planning to Populate Virtual Cities*, in "Autonomous Agents and Multiagent Systems", Saint Paul, United States, M. GINI, O. SHEHORY, I. TAKAYUKI, C. JONKER (editors), IFAAMAS, May 2013, pp. 1129-1130, <http://hal.inria.fr/hal-00913696>

- [24] *Best Paper*

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