2023
ACTIVITY REPORT

Project-Team
MIMETIC

Analysis-Synthesis Approach for Virtual Human Simulation

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA), Mouvement, Sport, Santé (M2S)

DOMAIN

Perception, Cognition and Interaction

THEME

Interaction and visualization

Ínría

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Keywords

Computer sciences and digital sciences

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A5.4.2. – Activity recognition

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Other research topics and application domains

B1.2.2. – Cognitive science

B2.5. – Handicap and personal assistances

B2.8. – Sports, performance, motor skills

B5.1. – Factory of the future

B5.8. – Learning and training

B9.2.2. – Cinema, Television

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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 behaviors, realistic motions and realistic interactions with other characters and users. It leads to modeling the complexity of a human body, as well as of his environment where he can pick up information and where he can act on it. A specific focus is dedicated to human physical activity and sports as it raises the highest constraints and 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 also includes 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 humans behave, move and interact in a natural manner in order to increase immersion and 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 beings. Moreover these characters have to deal with their environment. First, they have to perceive this environment and pick up relevant information. Thus, MimeTIC focuses on the problem of modeling the environment including its geometry and associated semantic information. Second, they have to act on this environment to reach their goals. It leads to cognitive processes, motion planning, joint coordination and force production in order to act on this environment.

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

- deal with the intrinsic complexity of human beings, 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,
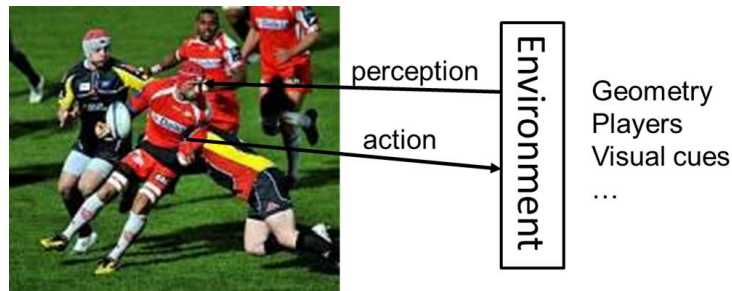
Figure 1: Main objective of MimeTIC: to better understand human activity in order to improve virtual human simulations. It involves modeling the complexity of human bodies, as well as of environments where to pick up information and act upon.

- make 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 measure human activity while balancing between ecological and controllable protocols, and to be able to extract relevant information in wide databases of information.

As opposed to many classical approaches in computer simulation, which mostly propose simulation without trying to understand how real people act, the team promotes a coupling between human activity analysis and synthesis, as shown in Figure 2.
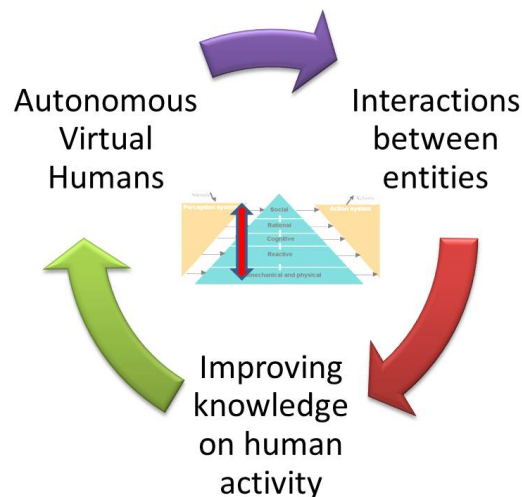
Figure 2: Research path of MimeTIC: coupling analysis and synthesis of human activity enables us to create more realistic autonomous characters and to evaluate assumptions about human motion control.

In this research path, **improving knowledge on human activity** allows 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 would in the same situation, it is possible to make them **interact with others**, i.e., autonomous characters (for crowds or group simulations) as well as 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,

- **interactions** in small and large groups of individuals, to understand and model interactions with lot of individual variability such as in crowds,

- **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 situations or selecting a natural motor behavior among the whole theoretical solution space for a given task,

- **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.

3   Research program

3.1   Biomechanics and Motion Control

Human motion control is a highly 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 exists an 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 an infinity of muscle activation patterns for a unique joint rotation. From the reactive point of view there exists an 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.

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 exists an infinity of muscle activation patterns, especially when dealing with antagonist muscles. An unresolved problem is to define how to use the above criteria to retrieve the actual activation patterns, while optimization approaches still leads to unrealistic ones. It is still an open problem that will require multidisciplinary skills including computer simulation, constraint solving, biomechanics, optimal control, physiology and neuroscience.

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 combinations of joint angles. In walking, data reduction techniques such as Principal Component
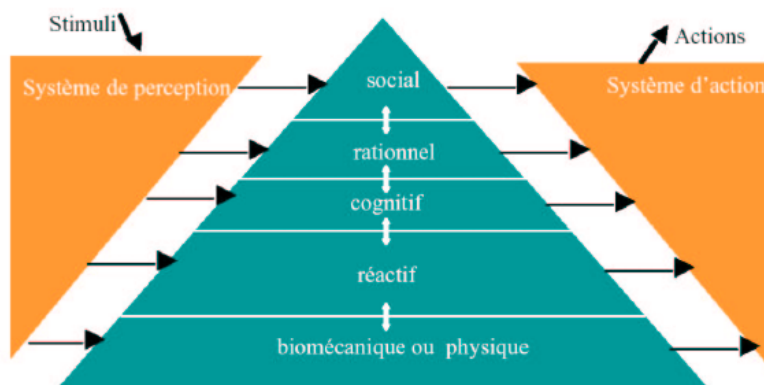
Figure 3: Layers of the motion control natural system in humans.

Analysis have shown that lower-limb joint angles are generally projected on a unique plane whose angle in the state space is associated with energy expenditure. Although knowledge exists for specific motions, 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.

Neuroscience also addresses 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 large 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 issue in this field is to navigate in an environment inhabited with other people. Typically, avoiding static obstacles along with other people moving inside that 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 allows us to contribute to enhance fundamental knowledge in human motion control.

3.2   Experiments in Virtual Reality

Understanding interactions between humans is 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, and it is therefore highly complex to understand their individual influence on these human interactions. 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 of 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 sessions, a real human acts in front of a camera and not in front of an opponent. That 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 enables 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 is picked up to make a decision. Moreover, cut-offs can also be used to obtain temporal information about when information is picked up. When the subject can react as in a 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 also allows the validation of 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. 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 into 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   Computer Animation

Computer animation is the branch of computer science devoted to models for the representation and simulation of the dynamic evolution of virtual environments. A first focus is the animation of virtual characters (behavior and motion). Through a deeper understanding of interactions using VR and through better perceptive, biomechanical and motion control models to simulate the evolution of dynamic systems, the Mimetic team has the ability to build more realistic, efficient and believable animations. Perceptual study also enables us to focus computation time on relevant information (i.e. leading to ensure natural motion from the perceptual points of view) and save time for unperceived details. The underlying challenges are (i) the computational efficiency of the system which needs to run in real-time in many situations, (ii) the capacity of the system to generalise/adapt to new situations for which data were not available, or models were not defined for, and (iii) the variability of the models, i.e. their ability to handle many body morphologies and generate variations in motions that would be specific to each virtual character.

In many cases, however, these challenges cannot be addressed in isolation. Typically, character behaviors also depend on the nature and the topology of the environment they are surrounded by. In essence, a character animation system should also rely on smarter representations of the environments, in order to better perceive the environment itself, and take contextualised decisions. Hence the animation of virtual characters in our context often requires to be coupled with models to represent the environment, to reason, and to plan both at a geometric level (can the character reach this location), and at a semantic level (should it use the sidewalk, the stairs, or the road). This represents the second focus. Underlying challenges are the ability to offer a compact -yet precise- representation on which efficient path, motion planning and high-level reasoning can be performed.

Finally, a third scientific focus is digital storytelling. Evolved representations of motions and environments enable realistic animations. It is yet equally important to question how these events should be portrayed, when and under which angle. In essence, this means integrating *discourse models* into *story models*, the story representing the sequence of events which occur in a virtual environment, and the discourse representing how this story should be displayed (i.e. which events to show in which order and with which viewpoint). Underlying challenges are pertained to:

- narrative discourse representations,

- projections of the discourse into the geometry, planning camera trajectories and planning cuts between the viewpoints,

- means to interactively control the unfolding of the discourse.

By therefore establishing the foundations to build bridges between the high-level narrative structures, the semantic/geometric planning of motions and events, and low-level character animations, the Mimetic team adopts a principled and all-inclusive approach to the animation of virtual characters.

4 Application domains

4.1 Animation, Autonomous Characters and Digital Storytelling

Computer Animation is one of the main application domains of the research work conducted in the MimeTIC team, in particular in relation to the entertainment and game industries. In these domains, creating virtual characters that are able to replicate real human motions and behaviours still highlights unanswered key challenges, especially as virtual characters are required to populate virtual worlds. For instance, virtual characters are used to replace secondary actors and generate highly populated scenes that would be hard and costly to produce with real actors. This requires to create high quality replicas that appear, move and behave both individually and collectively like real humans. The three key challenges for the MimeTIC team are therefore:

- to create natural animations (i.e., virtual characters that move like real humans),

- to create autonomous characters (i.e., that behave like real humans),

- to orchestrate the virtual characters so as to create interactive stories.

First, our challenge is to create animations of virtual characters that are natural, i.e. moving like a real human would. This challenge covers several aspects of Character Animation depending on the context of application, e.g., producing visually plausible or physically correct motions, producing natural motion sequences, etc. Our goal is therefore to develop novel methods for animating virtual characters, based on motion capture, data-driven approaches, or learning approaches. However, because of the complexity of human motion (number of degrees of freedom that can be controlled), resulting animations are not necessarily physically, biomechanically, or visually plausible. For instance, current physics-based approaches produce physically correct motions but not necessarily perceptually plausible ones. All these reasons are why most entertainment industries (gaming and movie production for example) still mainly rely on manual animation. Therefore, research in MimeTIC on character animation is also conducted with the goal of validating the results from objective standpoint (physical, biomechanical) as well as subjective one (visual plausibility).

Second, one of the main challenges in terms 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 scales and working with different natures of data, ranging from numerical (motion control, reactive behaviors) to symbolic (goal oriented behaviors, reasoning about actions and changes). For instance, autonomous characters play the role of actors that are driven by a scenario in video games and virtual storytelling. 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 kinds of situations. They enable to study new situations and their possible outcomes. In the MimeTIC team, our focus is therefore 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.

Finally, 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 itself 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.

4.2   Fidelity of Virtual Reality

VR is a powerful tool for perception-action experiments. VR-based experimental platforms allow exposing a population to fully controlled stimuli that can be repeated from trial to trial with high accuracy. Factors can be isolated and objects manipulations (position, size, orientation, appearance, ..) are easy to perform. Stimuli can be interactive and adapted to participants' responses. Such interesting features allow researchers to use VR to perform experiments in sports, motion control, perceptual control laws, spatial cognition as well as person-person interactions. However, the interaction loop between users and their environment differs in virtual conditions in comparison with real conditions. When a user interacts in an environment, movement from action and perception are closely related. While moving, the perceptual system (vision, proprioception,..) provides feedback about the users' own motion and information about the surrounding environment. That allows the user to adapt his/her trajectory to sudden changes in the environment and generate a safe and efficient motion. In virtual conditions, the interaction loop is more complex because it involves several material aspects.

First, the virtual environment is perceived through a numerical display which could affect the available information and thus could potentially introduce a bias. For example, studies observed a distance compression effect in VR, partially explained by the use of a Head Mounted Display with reduced field of view and exerting a weight and torques on the user's head. Similarly, the perceived velocity in a VR environment differs from the real world velocity, introducing an additional bias. Other factors, such as the image contrast, delays in the displayed motion and the point of view can also influence efficiency in VR. The second point concerns the user's motion in the virtual world. The user can actually move if the virtual room is big enough or if wearing a head mounted display. Even with a real motion, authors showed that walking speed is decreased, personal space size is modified and navigation in VR is performed with increased gait instability. Although natural locomotion is certainly the most ecological approach, the physical limited size of VR setups prevents from using it most of the time. Locomotion interfaces are therefore required. They are made up of two components, a locomotion metaphor (device) and a transfer function (software), that can also introduce bias in the generated motion. Indeed, the actuating movement of the locomotion metaphor can significantly differ from real walking, and the simulated motion depends on the transfer function applied. Locomotion interfaces cannot usually preserve all the sensory channels involved in locomotion.

When studying human behavior in VR, the aforementioned factors in the interaction loop potentially introduce bias both in the perception and in the generation of motor behavior trajectories. MimeTIC is working on the mandatory step of VR validation to make it usable for capturing and analyzing human motion.

4.3   Motion Sensing of Human Activity

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 problems 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.

First, we have studied how to recognize and quantify motions performed by a user when using accurate systems such as Vicon (product from Oxford Metrics), Qualisys, or Optitrack (product from 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 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, whose 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.

Second, we wish to find alternatives to the above approach which is based on analyzing accurate and complete knowledge of joint angles and positions. Hence new sensors, such as depth-cameras (Kinect, product from 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 some application domains that require picking specific information, such as gait asymmetry or regularity for clinical analysis of human walking.

4.4 Sports

Sport is characterized by complex displacements and motions. One main objective is to understand the determinants of performance through the analysis of the motion itself. In the team, different sports have been studied such as the tennis serve, where the goal was to understand the contribution of each segment of the body in the performance but also the risk of injuries as well as other situation in cycling, swimming, fencing or soccer. Sport motions are dependent on visual information that the athlete can pick up in his environment, including the opponent's actions. 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 sequentially 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 understand sports and interactions 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, in order to correctly anticipate the opponent's action.

4.5 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 VEs is to facilitate the design process, enhance the design efficiency, and reduce the costs.

The development of such platforms asks for several improvements in the field of motion analysis and VR. First, interactions have to be as natural as possible to properly mimic the motions performed in real environments. Second, the fidelity of the simulator also needs to be correctly evaluated. Finally, motion

analysis tools have to be able to provide in real-time biomechanics quantities usable by ergonomists to analyse and improve the working conditions.

In real working condition, motion analysis and musculoskeletal risk assessment raise also many scientific and technological challenges. Similarly to virtual reality, fidelity of the working process may be affected by the measurement method. Wearing sensors or skin markers, together with the need of frequently calibrating the assessment system may change the way workers perform the tasks. Whatever the measurement is, classical ergonomic assessments generally address one specific parameter, such as posture, or force, or repetitions..., which makes it difficult to design a musculoskeletal risk factor that actually represents this risk. Another key scientific challenge is then to design new indicators that better capture the risk of musculoskeletal disorders. However, this indicator has to deal with the trade-off between accurate biomechanical assessment and the difficulty to get reliable and required information in real working conditions.

4.6 Locomotion and Interactions between walkers

Modeling and simulating locomotion and interactions between walkers is a very active, complex and competitive domain, being investigating by various disciplines such as mathematics, cognitive sciences, physics, computer graphics, rehabilitation etc. Locomotion and interactions between walkers are by definition at the very core of our society since they represent the basic synergies of our daily life. When walking in the street, we should produce a locomotor movement while taking information about our surrounding environment in order to interact with people, move without collision, alone or in a group, intercept, meet or escape to somebody. MimeTIC is an international key contributor in the domain of understanding and simulating locomotion and interactions between walkers. By combining an approach based on Human Movement Sciences and Computer Sciences, the team focuses on locomotor invariants which characterize the generation of locomotor trajectories. We also conduct challenging experiments focusing on visuo-motor coordination involved during interactions between walkers both using real and virtual set-ups. One main challenge is to consider and model not only the "average" behaviour of healthy younger adult but also extend to specific populations considering the effect of pathology or the effect of age (kids, older adults). As a first example, when patients cannot walk efficiently, in particular those suffering from central nervous system affections, it becomes very useful for practitioners to benefit from an objective evaluation of their capacities. To facilitate such evaluations, we have developed two complementary indices, one based on kinematics and the other one on muscle 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. We extend this objective evaluation by using person-person interaction paradigm which allows studying visuo-motor strategies deficit in these specific populations.

Another fundamental question is the adaptation of the walking pattern according to anatomical constraints, such as pathologies in orthopedics, or adaptation to various human and non-human primates in paleoanthropoly. Hence, the question is to predict plausible locomotion according to a given morphology. This raises fundamental questions about the variables that are regulated to control gait: balance control, minimum energy, minimum jerk... In MimeTIC we develop models and simulators to efficiently test hypotheses on gait control for given morphologies.

5 Social and environmental responsibility

MimeTIC is not directly involved in environmental responsabilities.

6 Highlights of the year

6.1 Achievments

- **Team evaluation:** The team has been evaluated by three expert for the last time this year, ending a 12 years cycle for the project. The team has been recognized by the experts as a expert in sport sciences and physical activity analysis and synthesis.

- **Franck Multon status:** Franck Multon has been hired as Research Director by INRIA.

- **Olympic Games "Paris2024":** Many team members have been strongly involved in the scientific support of French Olympic teams training, and have carried-out dissemination of this research work in the wide public audience.

7   New software, platforms, open data

7.1   New software

7.1.1   AsymGait

Name: Asymmetry index for clinical gait analysis based on depth images

Keywords: Motion analysis, Kinect, Clinical analysis

Scientific Description: The system uses depth images delivered by the Microsoft Kinect to retrieve the gait cycles first. To this end it is based on a analyzing the knees trajectories instead of the feet to obtain more robust gait event detection. Based on these cycles, the system computes a mean gait cycle model to decrease the effect of noise of the system. Asymmetry is then computed at each frame of the gait cycle as the spatial difference between the left and right parts of the body. This information is computed for each frame of the cycle.

Functional Description: AsymGait is a software package that works with Microsoft Kinect data, especially depth images, in order to carry-out clinical gait analysis. First it identifies the main gait events using the depth information (footstrike, toe-off) to isolate gait cycles. Then it computes a continuous asymmetry index within the gait cycle. Asymmetry is viewed as a spatial difference between the two sides of the body.

Contact: Franck Multon

Participants: Edouard Auvinet, Franck Multon

7.1.2   Cinematic Viewpoint Generator

Keyword: 3D animation

Functional Description: The software, developed as an API, provides a mean to automatically compute a collection of viewpoints over one or two specified geometric entities, in a given 3D scene, at a given time. These viewpoints satisfy classical cinematographic framing conventions and guidelines including different shot scales (from extreme long shot to extreme close-up), different shot angles (internal, external, parallel, apex), and different screen compositions (thirds,fifths, symmetric of di-symmetric). The viewpoints allow to cover the range of possible framings for the specified entities. The computation of such viewpoints relies on a database of framings that are dynamically adapted to the 3D scene by using a manifold parametric representation and guarantee the visibility of the specified entities. The set of viewpoints is also automatically annotated with cinematographic tags such as shot scales, angles, compositions, relative placement of entities, line of interest.

Contact: Marc Christie

Participants: Christophe Lino, Emmanuel Badier, Marc Christie

Partners: Université d'Udine, Université de Nantes

7.1.3   CusToM

Name: Customizable Toolbox for Musculoskeletal simulation

Keywords: Biomechanics, Dynamic Analysis, Kinematics, Simulation, Mechanical multi-body systems

Scientific Description: The present toolbox aims at performing a motion analysis thanks to an inverse dynamics method.

Before performing motion analysis steps, a musculoskeletal model is generated. Its consists of, first, generating the desire anthropometric model thanks to models libraries. The generated model is then kinematical calibrated by using data of a motion capture. The inverse kinematics step, the inverse dynamics step and the muscle forces estimation step are then successively performed from motion capture and external forces data. Two folders and one script are available on the toolbox root. The Main script collects all the different functions of the motion analysis pipeline. The Functions folder contains all functions used in the toolbox. It is necessary to add this folder and all the subfolders to the Matlab path. The Problems folder is used to contain the different study. The user has to create one subfolder for each new study. Once a new musculoskeletal model is used, a new study is necessary. Different files will be automaticaly generated and saved in this folder. All files located on its root are related to the model and are valuable whatever the motion considered. A new folder will be added for each new motion capture. All files located on a folder are only related to this considered motion.

Functional Description: Inverse kinematics Inverse dynamics Muscle forces estimation External forces prediction

Publications: hal-02268958, hal-02088913, hal-02109407, hal-01904443, hal-02142288, hal-01988715, hal-01710990

Contact: Charles Pontonnier

Participants: Antoine Muller, Charles Pontonnier, Georges Dumont, Pierre Puchaud, Anthony Sorel, Claire Livet, Louise Demestre

7.1.4   Directors Lens Motion Builder

Keywords: Previzualisation, Virtual camera, 3D animation

Functional Description: Directors Lens Motion Builder is a software plugin for Autodesk's Motion Builder animation tool. This plugin features a novel workflow to rapidly prototype cinematographic sequences in a 3D scene, and is dedicated to the 3D animation and movie previsualization industries. The workflow integrates the automated computation of viewpoints (using the Cinematic Viewpoint Generator) to interactively explore different framings of the scene, proposes means to interactively control framings in the image space, and proposes a technique to automatically retarget a camera trajectory from one scene to another while enforcing visual properties. The tool also proposes to edit the cinematographic sequence and export the animation. The software can be linked to different virtual camera systems available on the market.

Contact: Marc Christie

Participants: Christophe Lino, Emmanuel Badier, Marc Christie

Partner: Université de Rennes 1

7.1.5   Kimea

Name: Kinect IMprovement for Egronomics Assessment

Keywords: Biomechanics, Motion analysis, Kinect

Scientific Description: Kimea consists in correcting skeleton data delivered by a Microsoft Kinect in an ergonomics purpose. Kimea is able to manage most of the occlultations that can occur in real working situation, on workstations. To this end, Kimea relies on a database of examples/poses organized as a graph, in order to replace unreliable body segments reconstruction by poses that have already been measured on real subject. The potential pose candidates are used in an optimization framework.

Functional Description: Kimea gets Kinect data as input data (skeleton data) and correct most of measurement errors to carry-out ergonomic assessment at workstation.

Publications: hal-01612939v1, hal-01393066v1, hal-01332716v1, hal-01332711v2, hal-01095084v1

Contact: Franck Multon

Participants: Franck Multon, Hubert Shum, Pierre Plantard

Partner: Faurecia

7.1.6 Populate

Keywords: Behavior modeling, Agent, Scheduling

Scientific Description: The software provides the following functionalities:

- A high level XML dialect that is dedicated to the description of agents activities in terms of tasks and sub activities that can be combined with different kind of operators: sequential, without order, interlaced. This dialect also enables the description of time and location constraints associated to tasks.

- An XML dialect that enables the description of agent's personal characteristics.

- An informed graph describes the topology of the environment as well as the locations where tasks can be performed. A bridge between TopoPlan and Populate has also been designed. It provides an automatic analysis of an informed 3D environment that is used to generate an informed graph compatible with Populate.

- The generation of a valid task schedule based on the previously mentioned descriptions.

With a good configuration of agents characteristics (based on statistics), we demonstrated that tasks schedules produced by Populate are representative of human ones. In conjunction with TopoPlan, it has been used to populate a district of Paris as well as imaginary cities with several thousands of pedestrians navigating in real time.

Functional Description: Populate is a toolkit dedicated to task scheduling under time and space constraints in the field of behavioral animation. It is currently used to populate virtual cities with pedestrian performing different kind of activities implying travels between different locations. However the generic aspect of the algorithm and underlying representations enable its use in a wide range of applications that need to link activity, time and space. The main scheduling algorithm relies on the following inputs: an informed environment description, an activity an agent needs to perform and individual characteristics of this agent. The algorithm produces a valid task schedule compatible with time and spatial constraints imposed by the activity description and the environment. In this task schedule, time intervals relating to travel and task fulfillment are identified and locations where tasks should be performed are automatically selected.

Contact: Fabrice Lamarche

Participants: Carl-Johan Jorgensen, Fabrice Lamarche

7.1.7 PyNimation

Keywords: Moving bodies, 3D animation, Synthetic human

Scientific Description: PyNimation is a python-based open-source (AGPL) software for editing motion capture data which was initiated because of a lack of open-source software enabling to process different types of motion capture data in a unified way, which typically forces animation pipelines to rely on several commercial software. For instance, motions are captured with a software, retargeted using another one, then edited using a third one, etc. The goal of Pynimation is therefore to bridge the gap in the animation pipeline between motion capture software and final game engines, by handling in a unified way different types of motion capture data, providing standard and novel motion editing solutions, and exporting motion capture data to be compatible with common 3D game engines (e.g., Unity, Unreal). Its goal is also simultaneously to provide support to our research efforts in this area, and it is therefore used, maintained, and extended to progressively include novel motion editing features, as well as to integrate the results of our research projects. At a short term, our goal is to further extend its capabilities and to share it more largely with the animation/research community.

Functional Description: PyNimation is a framework for editing, visualizing and studying skeletal 3D animations, it was more particularly designed to process motion capture data. It stems from the wish to utilize Python's data science capabilities and ease of use for human motion research.

In its version 1.0, Pynimation offers the following functionalities, which aim to evolve with the development of the tool : - Import / Export of FBX, BVH, and MVNX animation file formats - Access and modification of skeletal joint transformations, as well as a certain number of functionalities to manipulate these transformations - Basic features for human motion animation (under development, but including e.g. different methods of inverse kinematics, editing filters, etc.). - Interactive visualisation in OpenGL for animations and objects, including the possibility to animate skinned meshes

URL: https://gitlab.inria.fr/lhoyet/pynimation

Authors: Ludovic Hoyet, Robin Adili, Benjamin Niay, Alberto Jovane

Contact: Ludovic Hoyet

7.1.8 The Theater

Keywords: 3D animation, Interactive Scenarios

Functional Description: The Theater is a software framework to develop interactive scenarios in virtual 3D environements. The framework provides means to author and orchestrate 3D character behaviors and simulate them in real-time. The tools provides a basis to build a range of 3D applications, from simple simulations with reactive behaviors, to complex storytelling applications including narrative mechanisms such as flashbacks.

Contact: Marc Christie

Participant: Marc Christie

7.2 New platforms

7.2.1 Immerstar Platform

Participants: Georges Dumont *(contact)*, Ronan Gaugne, Anthony Sorel, Richard Kulpa.

With the two platforms of virtual reality, Immersia) and Immermove Immermove, grouped under the name Immerstar, the team has access to high level scientific facilities. This equipment benefits the research teams of the center and has allowed them to extend their local, national and international collaborations. The Immerstar platform was granted by a Inria CPER funding for 2015-2019 that enabled important evolutions of the equipment. In 2016, the first technical evolutions have been decided and, in 2017, these evolutions have been implemented. On one side, for Immermove, the addition of a third face to the immersive space, and the extension of the Vicon tracking system have been realized and continued this year with 23 new cameras. And, on the second side, for Immersia, the installation of WQXGA laser projectors with augmented global resolution, of a new tracking system with higher frequency and of new computers for simulation and image generation in 2017. In 2018, a Scale One haptic device has been installed. It allows, as in the CPER proposal, one or two handed haptic feedback in the full space covered by Immersia and possibility of carrying the user. Based on these supports, in 2020, we participated to a PIA3-Equipex+ proposal. This proposal CONTINUUM involves 22 partners, has been succesfully evaluated and will be granted. The CONTINUUM project will create a collaborative research infrastructure of 30 platforms located throughout France, to advance interdisciplinary research based on interaction between computer science and the human and social sciences. Thanks to CONTINUUM, 37 research teams will develop cutting-edge research programs focusing on visualization, immersion, interaction and collaboration, as well as on human perception, cognition and behaviour in virtual/augmented reality, with potential impact on societal issues. CONTINUUM enables a paradigm shift in the way we perceive, interact, and collaborate with complex digital data and digital worlds by putting humans at the center of the data processing workflows. The project will empower scientists, engineers and industry users with a highly interconnected network of high-performance visualization and immersive platforms to observe, manipulate, understand and share digital data, real-time multi-scale simulations, and virtual or augmented experiences. All platforms will feature facilities for remote collaboration with other platforms, as well as mobile equipment that can be lent to users to facilitate onboarding. The kick-off meeting of continuum has been held in 2022, January the 14th. A global meeting was held in 2022, July the 5th and 6th.

8 New results

8.1 Outline

In 2023, MimeTIC has maintained its activity in motion analysis, modelling and simulation, to support the idea that these approaches are strongly coupled in a motion analysis-synthesis loop. This idea has been applied to the main application domains of MimeTIC:

- Animation, Autonomous Characters and Digital Storytelling,

- Motion sensing of Human Activity,

- Sports,

- Ergonomics,

- Locomotion and Interactions Between Walkers.

8.2 Animation, Autonomous Characters and Digital Storytelling

MimeTIC main research path consists in associating motion analysis and synthesis to enhance the naturalness in computer animation, with applications in camera control, movie previsualisation, and autonomous virtual character control. Thus, we pushed example-based techniques in order to reach a good trade-off between simulation efficiency and naturalness of the results. In 2022, to achieve this goal, MimeTIC continued to explore the use of perceptual studies and model-based approaches, but also began to investigate deep learning to generate plausible behaviors.

8.2.1 MAAIP: Multi-Agent Adversarial Interaction Priors for imitation from fighting demonstrations for physics-based characters

Participants: Mohamed Younes, Franck Multon *(contact)*, Richard Kulpa.
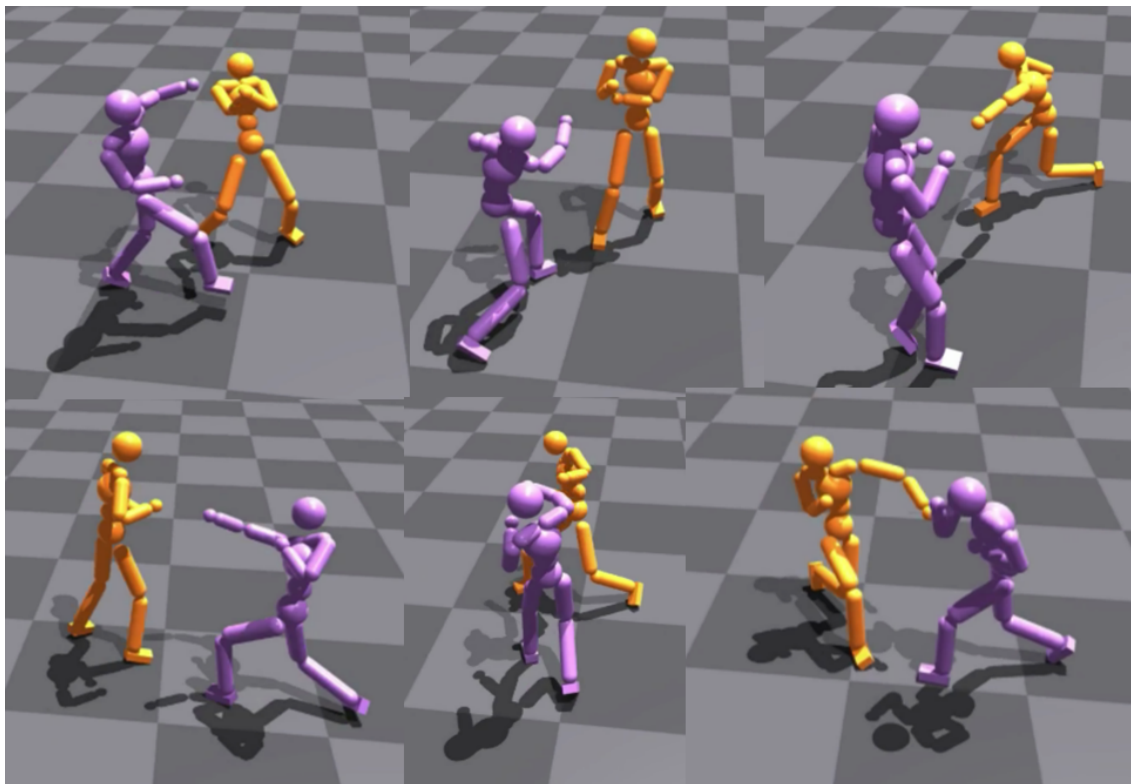
Figure 4: Simulated shadowboxing interactions between two physics-based characters.

Simulating realistic interaction and motions for physics-based characters is of great interest for interactive applications, and automatic secondary character animation in the movie and video game industries. Recent works in reinforcement learning have proposed impressive results for single character simulation, especially the ones that use imitation learning based techniques. However, imitating multiple characters interactions and motions requires to also model their interactions. In this paper, we propose a novel Multi-Agent Generative Adversarial Imitation Learning based approach that generalizes the idea of motion imitation for one character to deal with both the interaction and the motions of the multiple physics-based characters [25]. Two unstructured datasets are given as inputs: 1) a single-actor dataset containing motions of a single actor performing a set of motions linked to a specific application, and 2) an interaction dataset containing a few examples of interactions between multiple actors. Based on these datasets, our system trains control policies allowing each character to imitate the interactive skills associated with each actor, while preserving the intrinsic style. This approach has been tested on two different fighting styles, boxing and full-body martial art, to demonstrate the ability of the method to imitate different styles.

8.3 Motion Sensing of Human Activity

MimeTIC has a long experience in motion analysis in laboratory condition. In the MimeTIC project, we proposed to explore how these approaches could be transferred to ecological situations, with a lack of control on the experimental conditions. In 2022, we continued to explore the use of deep learning

techniques to capture human performance based on simple RGB or depth images. We also continued exploring how customizing complex musculoskeletal models with simple calibration processes. We also investigated the use of machine learning to access parameters that could not be measured directly.

8.3.1 Evaluation of hybrid deep learning and optimization method for 3D human pose and shape reconstruction in simulated depth images

Participants: Adnane Boukhayma, Franck Multon *(contact)*.
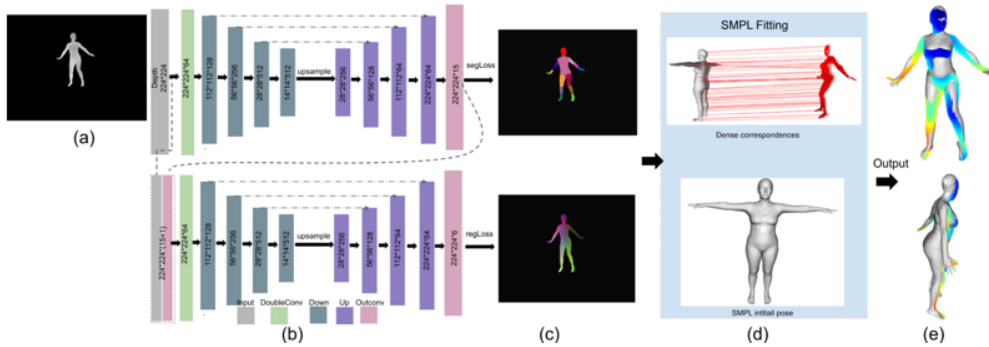

Figure 5: (a) Input depth image, b) DoubleUnet, stacked two Unets to infer segmentation and color map regression; c) embedded color: first three channels encode human part, last-three channels encode pixel normalized distance; d) SMPL fitting e) Outputs : 3D human shape.

In 2022, we addressed the problem of capturing both the shape and the pose of a character using a single depth sensor. Some previous works proposed to fit a parametric generic human template in the depth image, while others developed deep learning (DL) approaches to find the correspondence between depth pixels and vertices of the template. In this paper, we explore the possibility of combining these two approaches to benefit from their respective advantages. The hypothesis is that DL dense correspondence should provide more accurate information to template model fitting, compared to previous approaches which only use estimated joint position only. Thus, we stacked a state-of-the-art DL dense correspondence method (namely double U-Net) and parametric model fitting (namely Simplify-X). The experiments on the SURREAL [1], DFAUST datasets [2] and a subset of AMASS [3], show that this hybrid approach enables us to enhance pose and shape estimation compared to using DL or model fitting separately. This result opens new perspectives in pose and shape estimation in many applications where complex or invasive motion capture set-ups are impossible, such as sports, dance, ergonomic assessment, etc.

In 2023, we more deeply evaluated this method and its ability to segment backgroud in complex simulated depth images [24]. Results show that this hybrid approach enables us to enhance pose and shape estimation compared to using DL or model fitting separately. We also evaluated the ability of the DL-based dense correspondence method to segment also the background - not only the body parts. We also evaluated 4 different methods to perform the model fitting based on a dense correspondence, where the number of available 3D points differs from the number of corresponding template vertices. These two results enabled us to better understand how to combine DL and model fitting, and the potential limits of this approach to deal with real depth images. Future works could explore the potential of taking temporal information into account, which has proven to increase the accuracy of pose and shape reconstruction based on a unique depth or RGB image.

This work was part of the European project SCHEDAR, funded by ANR, and leaded by Cyprus University. This work was performed in collaboration with University of Reims Champagne Ardennes.

8.3.2 Robustifying Generalizable Implicit Shape Networks with a Tunable Non-Parametric Model

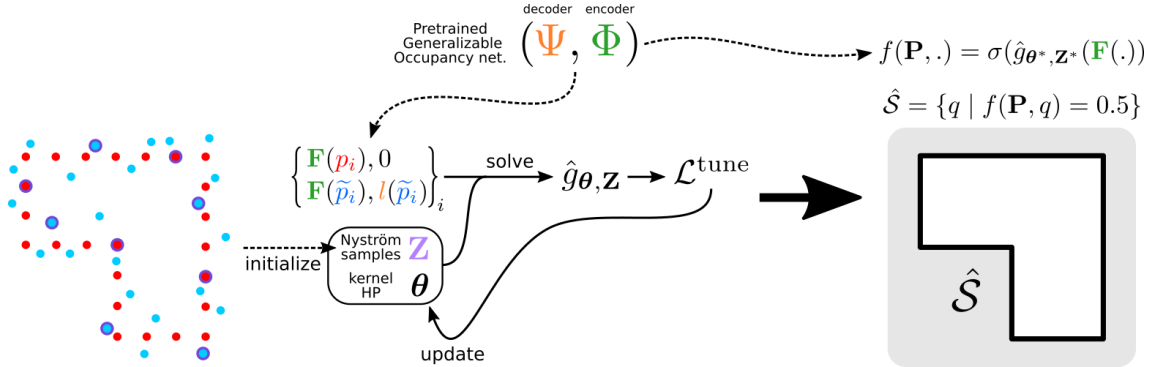**Participants:**   Adnane Boukhayma *(contact)*, Amine Ouasfi.

Figure 6: Overview. Our method predicts an implicit shape function from a noisy unoriented input point cloud. We combine a cross-shape deep prior (Pretrained generalizable occupancy network) and an intra-shape adaptive Nystrom Kernel Ridge Regression (NKRR) *g* at test time. The latter learns to map network features of the input points and additional points to the level-set and network generated pseudo-labels respectively. The NKRR hyperparameters (Z,θ) are adjusted to the current shape.

Feedforward generalizable models for implicit shape reconstruction from unoriented point cloud present multiple advantages, including high performance and inference speed. However, they still suffer from generalization issues, ranging from underfitting the input point cloud, to misrepresenting samples outside of the training data distribution, or with toplogies unseen at training. We propose here an efficient mechanism to remedy some of these limitations at test time. We combine the inter-shape data prior of the network with an intra-shape regularization prior of a Nyström Kernel Ridge Regression, that we further adapt by fitting its hyperprameters to the current shape. The resulting shape function defined in a shape specific Reproducing Kernel Hilbert Space benefits from desirable stability and efficiency properties and grants a shape adaptive expressiveness-robustness trade-off. We demonstrate the improvement obtained through our method with respect to baselines and the state-of-the-art using synthetic and real data.

8.3.3   Mixing-Denoising Generalizable Occupancy Networks

Participants: Adnane Boukhayma *(contact)*, Amine Ouasfi.

While current state-of-the-art generalizable implicit neural shape models rely on the inductive bias of convolutions, it is still not entirely clear how properties emerging from such biases are compatible with the task of 3D reconstruction from point cloud. We explore an alternative approach to generalizability in this context. We relax the intrinsic model bias (i.e. using MLPs to encode local features as opposed to convolutions) and constrain the hypothesis space instead with an auxiliary regularization related to the reconstruction task, i.e. denoising. The resulting model is the first only-MLP locally conditioned implicit shape reconstruction from point cloud network with fast feed forward inference. Point cloud borne features and denoising offsets are predicted from an exclusively MLP-made network in a single forward pass. A decoder predicts occupancy probabilities for queries anywhere in space by pooling nearby features from the point cloud order-invariantly, guided by denoised relative positional encoding. We outperform the state-of-the-art convolutional method while using half the number of model parameters.

8.3.4   Few-Shot Multi-Human Neural Rendering Using Geometry Constraints
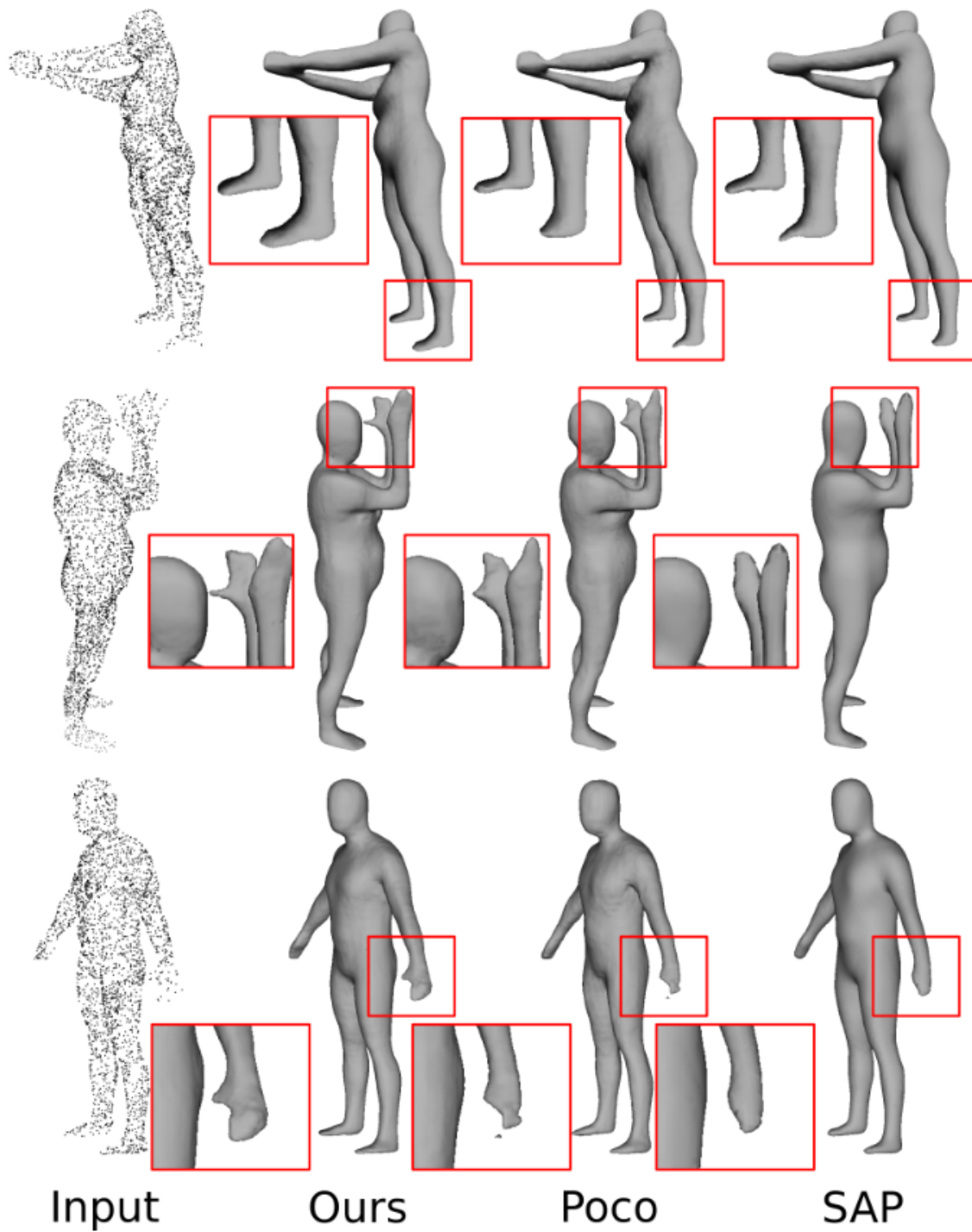
Figure 7: Reconstruction examples as obtained with our method and the competition, from a sparse unoriented noisy point cloud.

Participants: Adnane Boukhayma *(contact)*, Qian Li, Franck Multon.

We present a method for recovering the shape and radiance of a scene consisting of multiple people
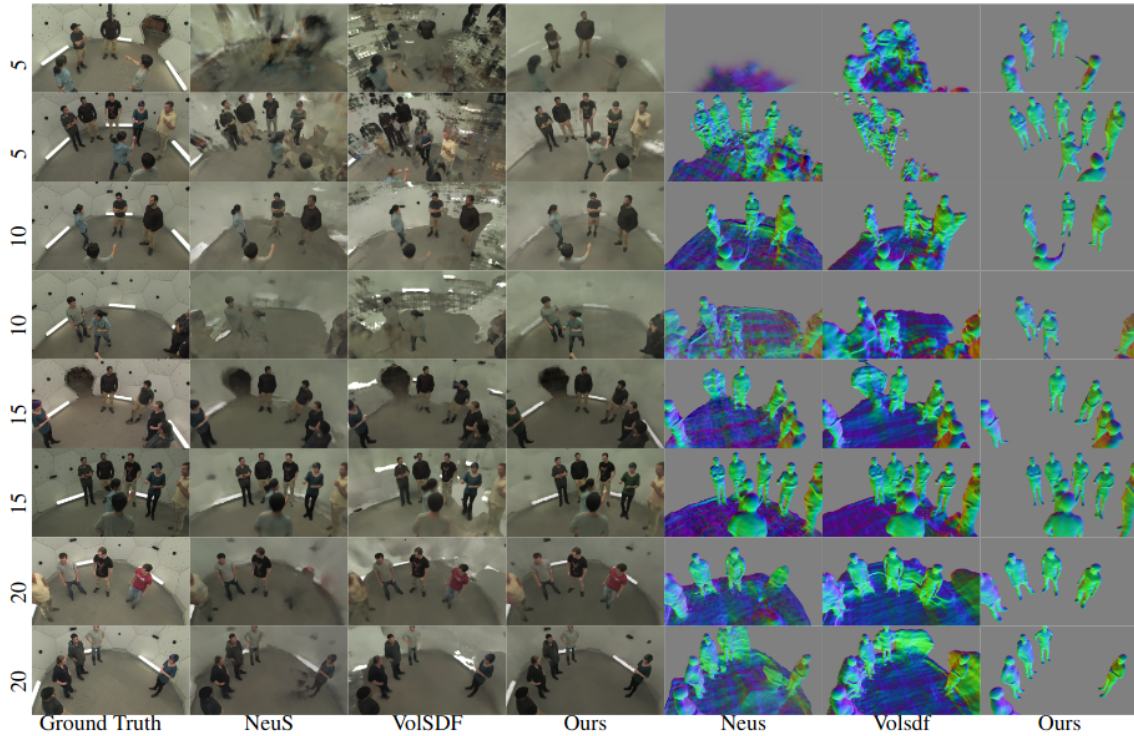
Figure 8: Qualitative comparison of novel view and reconstruction obtained through our method and sota methods, given a few input images (5,10,20)

given solely a few images. Multi-human scenes are complex due to additional occlusion and clutter. For single-human settings, existing approaches using implicit neural representations have achieved impressive results that deliver accurate geometry and appearance. However, it remains challenging to extend these methods for estimating multiple humans from sparse views. We propose a neural implicit reconstruction method that addresses the inherent challenges of this task through the following contributions: First, we use geometry constraints by exploiting pre-computed meshes using a human body model (SMPL). Specifically, we regularize the signed distances using the SMPL mesh and leverage bounding boxes for improved rendering. Second, we created a ray regularization scheme to minimize rendering inconsistencies, and a saturation regularization for robust optimization in variable illumination. Extensive experiments on both real and synthetic datasets demonstrate the benefits of our approach and show state-of-the-art performance against existing neural reconstruction methods.

8.3.5 Contact-conditioned hand-held object reconstruction from single-view images

Participants: Adnane Boukhayma *(contact)*.

Reconstructing the shape of hand-held objects from single-view color images is a long-standing problem in computer vision and computer graphics. The task is complicated by the ill-posed nature of single-view reconstruction, as well as potential occlusions due to both the hand and the object. Previous works mostly handled the problem by utilizing known object templates as priors to reduce the complexity. In contrast, our paper proposes a novel approach without knowing the object templates beforehand but by exploiting prior knowledge of contacts in hand-object interactions to train an attention-based network that can perform precise hand-held object reconstructions with only a single forward pass in inference. The network we propose encodes visual features together with contact features using a multi-head attention module as a way to condition the training of a neural field representation. This neural field representation

Figure 9: Reconstruction examples obtained with our method from a single image.

outputs a Signed Distance Field representing the reconstructed object and extensive experiments on three well-known datasets demonstrate that our method achieves superior reconstruction results even under severe occlusion compared to the state-of-the-art techniques.

8.3.6 Regularizing Neural Radiance Fields from Sparse RGBD Inputs

Participants: Adnane Boukhayma *(contact)*, Qian Li, Franck Multon.

This paper aims at improving neural radiance fields (NeRF) from sparse inputs. NeRF achieves photo-realistic renderings when given dense inputs, while its' performance drops dramatically with the decrease of training views' number. Our insight is that the standard volumetric rendering of NeRF is prone to over-fitting due to the lack of overall geometry and local neighborhood information from limited inputs. To address this issue, we propose a global sampling strategy with a geometry regularization utilizing warped images as augmented pseudo-views to encourage geometry consistency across multi-views. In addition, we introduce a local patch sampling scheme with a patch-based regularization for appearance consistency. Furthermore, our method exploits depth information for explicit geometry regularization. The proposed approach outperforms existing baselines on real benchmarks DTU datasets from sparse inputs and achieves the state of art results.

8.3.7 Learning Generalizable Light Field Networks from Few Images

Participants: Adnane Boukhayma *(contact)*, Qian Li, Franck Multon.
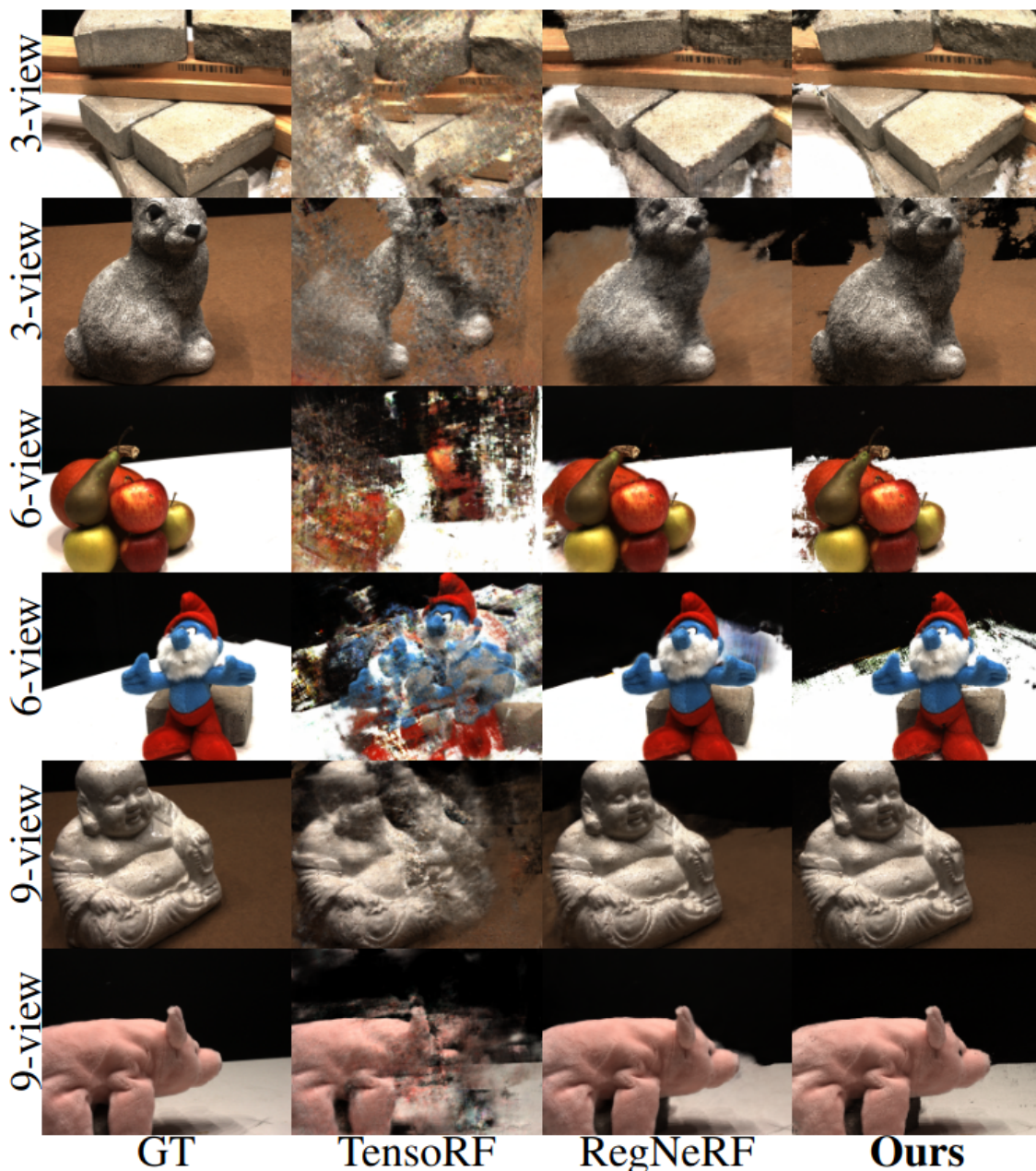
Figure 10: Qualitative comparison to sota competition.

We explore a new strategy for few-shot novel view synthesis based on a neural light field representation. Given a target camera pose, an implicit neural network maps each ray to its target pixel color directly. The network is conditioned on local ray features generated by coarse volumetric rendering from an explicit 3D feature volume. This volume is built from the input images using a 3D ConvNet. Our method achieves competitive performances on synthetic and real MVS data with respect to state-of-the-art neural radiance field based competition, while offering a 100 times faster rendering.

8.3.8   Few 'Zero Level Set'-Shot Learning of Shape Signed Distance Functions in Feature Space
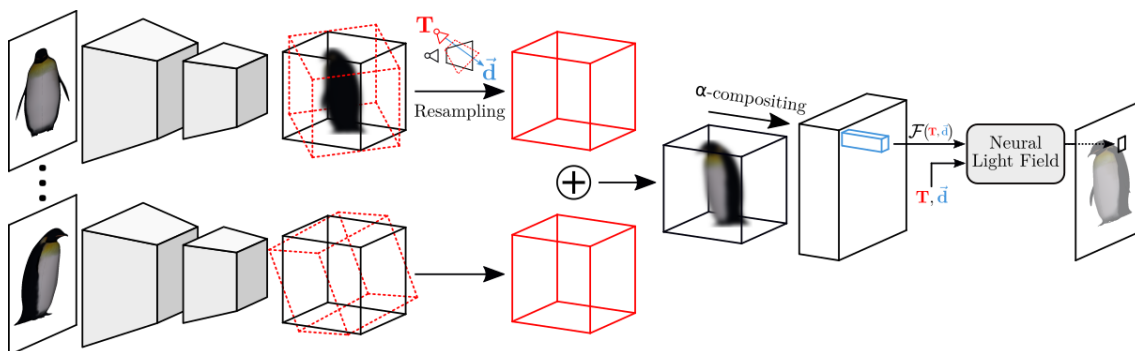
Figure 11: Overview of our method. Given an input image, a 3D feature volume is built with a convolutional neural network (first black cube). The volume represents features inside the input view frustum. Given a target view, these features are resampled into a volume representing the target view frustum (red cube). Target feature volumes originating from different input views are aggregated using learnable weights. An image of ray features is produced by rendering the target aggregated feature volume with alpha-compositing. Finally the light field network maps a ray stemming from a target camera origin T and spanning a direction d, along with its convolutional feature F, to the corresponding pixel color of the target image

Participants: Adnane Boukhayma *(contact)*, Amine Ouasfi.

We explore a new idea for learning based shape reconstruction from a point cloud, based on the recently popularized implicit neural shape representations. We cast the problem as a few-shot learning of implicit neural signed distance functions in feature space, that we approach using gradient based meta-learning. We use a convolutional encoder to build a feature space given the input point cloud. An implicit decoder learns to predict signed distance values given points represented in this feature space. Setting the input point cloud, i.e. samples from the target shape function's zero level set, as the support (i.e. context) in few-shot learning terms, we train the decoder such that it can adapt its weights to the underlying shape of this context with a few (5) tuning steps. We thus combine two types of implicit neural network conditioning mechanisms simultaneously for the first time, namely feature encoding and meta-learning. Our numerical and qualitative evaluation shows that in the context of implicit reconstruction from a sparse point cloud, our proposed strategy, i.e. meta-learning in feature space, outperforms existing alternatives, namely standard supervised learning in feature space, and meta-learning in euclidean space, while still providing fast inference.

8.3.9   Pressure insoles assessment for external forces prediction

Participants: Pauline Morin, Georges Dumont *(contact)*, Charles Pontonnier *(contact)*.

Force platforms generally involves a costraint to analyze human movement in the laboratory. Promising methods for estimating ground reaction forces and moments (GRF&M) can overcome this limitation. The most effective family of methods consists of minimizing a cost, constrained by the subject's dynamic equilibrium, for distributing the force over the contact surface on the ground. The detection of contact surfaces over time is dependent on numerous parameters. In this work we proposed to evaluate two contact detection methods: the first based on foot kinematics and the second based on pressure sole data. Optimal parameters for these two methods were identified for walking, running, and sidestep cut tasks. The results show that a single threshold in position or velocity is sufficient to guarantee a good estimate. Using pressure sole data to detect contact improves the estimation of the position of the center
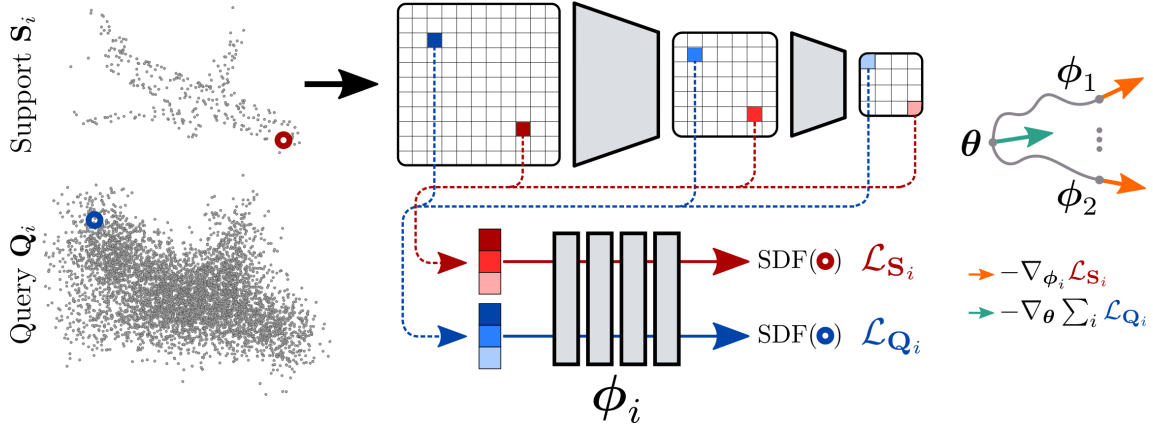
Figure 12: Overview of our method. Our input is a sparse point cloud (Support $\mathbf{S}_i$) and our output is an implicit neural SDF f. f is a neural network comprised of a convolutional encoder (top in gray) and an MLP decoder (bottom in gray). The decoder predicts SDF values for 3D points (red/blue circles) through their spatially sampled features (squares in shades of red/blue) from the encoder's activation maps. Following a gradient-based few-shot learning algorithm (MAML), we learn a meta-decoder in encoder feature space, parameterized with θ, that can quickly adapt to a new shape, i.e. new parameters ϕ_i, given its support. This is achieved by iterating per-shape 5-step adaptation gradient descent (orange arrow) using the support loss $\mathscr{L}_{S_i}$, and one-step meta gradient-descent (green arrow) by back-propagating the Query set (Q_i) loss $\mathscr{L}_{Q_i}$ evaluated with the specialized parameters ϕ_i w.r.t. the meta-parameters θ. At test time, 5 fine-tuning iterations are performed similarly starting from the converged meta-model to evaluate f.

of pressure (CoP). Both methods demonstrated a similar level of accuracy in estimating ground reaction forces [17].

8.4   Sports

MimeTIC promotes the idea of coupling motion analysis and synthesis in various domains, especially sports. More specifically, we have a long experience and international leadership in using Virtual Reality for analyzing and training sports performance. In 2022, we continued to explore how enhancing the use of VR to design original training system. More specifically we addressed the problem of early motion recognition to make a virtual opponent react to the user's action before it ends. We also worked on the behavioral animation of the virtual athletes. Finally, we used VR as a mean to analyze perception in sports, or to train anticipation skills by introducing visual artifacts in the VR experience.

We also initiated some simulation work to better characterize the interaction between a user and his physical environment, such as interactions between swimmers and diving boards.

8.4.1   VR for training perceptual-motor skills of boxers and relay runners for Paris 2024 Olympic games

Participants: Richard Kulpa *(contact)*, Annabelle Limballe.

The revolution in digital technologies, and in particular Virtual Reality, in the field of sport has opened up new perspectives for the creation of new modalities for analyzing and training the skills underlying performance. Virtual Reality allows for the standardization, control and variation (even beyond real conditions) of stimuli while simultaneously quantifying performance. This provides the opportunity to offer specific training sessions, complementary to traditional training ones. In addition, in order to

continuously improve their performances, athletes need to train more and more but they may reach their physical limits. Virtual Reality can create new training modalities that allow them to continue training while minimising the risk of injury (for example, due to the repetition of high-intensity work in races for a 4x100m relay or due to the impacts of defensive training in boxing). It may also be relevant for injured athletes who cannot physically practice their discipline but need to continue to train perceptually and cognitively by confronting field situations. In a series of publications, we described how Virtual Reality is effectively implemented in the French Boxing and Athletics federations to train athletes' anticipation skills in their preparation for the Paris 2024 Olympic Games. In the 4x100m relay [32, 35], the team's performance partly depends on the athletes' ability to synchronize their movements and therefore initiate their race at the right moment, before the partner arrives in the relay transmission zone, despite the pressure exerted by the opponents. The Virtual Reality training protocols are therefore designed to train each athlete to initiate his or her race at the right moment, with a tireless and always available avatar, based on the motion capture of real sprinters, whose race characteristics can be configured in terms of speed, lane, curvature, gender, etc. In boxing [33], the federation wants to improve boxers' anticipation skills in defensive situations without making them undergo repetitive blows that could injure them, which is impossible in real training. Virtual Reality training protocols allow boxers to focus on the appropriate information on the opponent, which should enable them to anticipate attacks and adopt the relevant parry. In this talk we will therefore show how these different challenges can be addressed in the REVEA project through the deployment of an interdisciplinary research programme.

8.4.2 Acceptance of VR training tools in high-level sport

Participants: Richard Kulpa *(contact)*.

Under certain conditions, immersive virtual reality (VR) has shown its effectiveness in improving sport performance. However, the psychological impact of VR on athletes is often overlooked, even though it can be deleterious (e.g., decreased performance, stopping the use of VR). We have recently highlighted a significant intention of athletes to use a VR Head Mounted Display (VR-HMD) designed to increase their sport performance [34, 40]. Whatever their level is, before a first use, they all initially considered it as quite useful (except for recreational athletes), quite easy to use, and quite pleasant to use. Coaches are also concerned by using the VR-HMD: If athletes accept the VR-HMD but coaches do not, there is a risk that the VR-HMD will never be used despite its potential benefits. In this context and based on the Technology Acceptance Model, a second study aimed at identifying possible blockages by measuring coaches' acceptance of VR-HMD device before the first use [39]. A total of 239 coaches, from different sports and from local to international level, filled out a questionnaire assessing perceived usefulness to improve training, perceived usefulness to improve athletes' performance, perceived ease of use, perceived enjoyment, job relevance, and coaches' intention to use it. Structural equation modeling analysis, one-sample t-tests, and one-way ANOVAs were used to examine the data. The main results show that (1) coaches' intention to use the VR-HMD is positively predicted by perceived usefulness to improve athletes' performance, perceived enjoyment, and job relevance, but not by perceived ease of use, (2) coaches significantly consider the VR-HMD useful to include in their training and to improve their athletes' performance, easy to use, pleasant to use, and relevant for their job, and (3) no significant differences appear on the previous scores according to coaches' levels, except for job relevance: international and national coaches find the VR-HMD more relevant to their job than local level coaches. All these results highlight that the VR-HMD is rather well accepted by the coaches before a first use.

8.4.3 Multiple Players Tracking in Virtual Reality: Influence of Soccer Specific Trajectories and Relationship With Gaze Activity

Participants: Richard Kulpa *(contact)*, Anthony Sorel, Annabelle Limballe, Benoit Bideau, Alexandre Vu.

The perceptual-cognitive ability to track multiple moving objects and its contribution to team sports performance has traditionally been studied in the laboratory under non-sports specific conditions. It is thus questionable whether the measured visual tracking performance and the underlying gaze activity reflected the actual ability of team sports players to track teammates and opponents on a real field. Using a Virtual Reality-based visual tracking task, the ability of participants to track multiple moving virtual players as they would do on a soccer field was observed to pursue two objectives. (i) See the influence of different scenario types (soccer-specific trajectories versus pseudo-random trajectories) on the visual tracking performance of soccer (n = 15) compared to non-soccer players (n = 16). (ii) Observe the influence of spatial features of the simulated situations on gaze activity between soccer players and non-soccer players. (i) The linear mixed model regression revealed a significant main effect of the group but no interaction effect between group and the type of trajectories, suggesting that the visual tracking ability of soccer players did not benefit from their specific knowledge when they faced scenarios with real game trajectories. (ii) Virtual players' spatial dispersion and crowding affected the participants' gaze activity and their visual tracking performance. Furthermore, the gaze activity of soccer players differed in some aspects from the gaze activity of non-soccer players. Assumptions are formulated as to the implication of these results in the difference in visual tracking performance between soccer players and non-soccer players. Overall, using soccer-specific trajectories might not be enough to replicate the representativeness of the field conditions in the study of visual tracking performance [7]. Multitasking constraints should be considered along with motor-cognitive dual-tasks in future research to develop the representativeness of visual exploration conditions.

8.4.4   Using Blur for Perceptual Investigation and Training in Sport? A Clear Picture of the Evidence and Implications for Future Research

Participants: Richard Kulpa *(contact)*, Annabelle Limballe.

Dynamic, interactive sports require athletes to identify, pick-up and process relevant information in a very limited time, in order to then make an appropriate response. Perceptual-cognitive skills are, therefore, a key determinant of elite sporting performance. Recently, sport scientists have investigated ways to assess and train perceptual-cognitive skills, with one such method involving the use of blurred stimuli. Here, we describe the two main methods used to generate blur (i.e., dioptric and Gaussian) and then review the current findings in a sports context [4]. Overall, it has been shown the use of blur can enhance performance and learning of sporting tasks in novice participants, especially when the blur is applied to peripheral stimuli. However, while intermediate and expert level participants are relatively impervious to the presence of blur, it remains to be determined if they are positive effects on learning. In a final section, we describe some of the methodological issues that limit the application of blur and then discuss the potential use of virtual reality to extend the current research base in sporting contexts.

8.4.5   Spatio-Temporal Convolutional Neural Networks for the analysis and early recognition of actions and gestures

Participants: Richard Kulpa *(contact)*, William Mocaer.

This research work focuses on the early recognition of gestures in the field of human machine interaction. The primary challenge addressed in this study is the development of a versatile approach for recognizing both 2D gestures performed on a tablet and 3D gestures executed by the human body. To ensure smooth interaction and responsiveness in both domains, the main goal is to recognize these gestures as early as possible, ideally before they are completed. The contributions of this research are structured around three axes: gesture representation, the implementation of a deep learning-based recognition system, and the design of a decision mechanism. These three components work together within a system capable of recognizing a gesture in progress early, while also refraining from making a

decision until a gesture becomes distinguishable due to ambiguity between multiple gestures. These approaches proved to be effective in evaluations, both in the trimmed context for 2D gestures and in the untrimmed context for 2D and 3D gestures. The results and experiments of this research demonstrate the relevance of these approaches for real-time interactive systems [37].

8.4.6 Diving analysis

Participants: Georges Dumont *(contact)*, Charles Pontonnier, Guillaume Nicolas, Nicolas Bideau, Louise Demestre, Pauline Morin.

In this study we studied the biomechanical indicators of perfomance during the final push of an elite diver. We used our previous work on the athlete-diving board interaction to characterize biomechanical quantities and compared them to the performance realized during several trials judged by a professionnal [13].

8.4.7 In-situ motion analysis during swimming training and competition

Participants: Nicolas Bideau *(contact)*, Guillaume Nicolas, Benoit Bideau.

There is a growing trend in swimming, as in many other sports, to monitor human technical skills, and performance during in situ training and competition. To do so, several devices and sensors are becoming more readily available for athletes and allow performance to be quantified more precisely. However, conventional devices such as cameras in swimming suffer from optical occlusions and cumbersome non-automatic data processing making reliable assessment hard to achieve in real conditions.Thus, we developed a deep learning model devoted to the analysis of swimming using a single Inertial Measurement Unit (IMU) attached to the sacrum. The proposed method took high inter- and intra-swimmer variability into account and was set up for the purpose of predicting eight swimming classes at several swimming velocities ranging from low to maximal. The method is able to automatically analyze swimmers with various levels of expertise in the context of in situ training monitoring.

Moreover, race analysis in swimming can support the guidance of training and the adjustment of race strategy through provision of feedbacks to coach. However, in-situ assessment of stroke mechanics in open water swimming is largely constrained by several factors (motion on a large outdoor area, mass start configuration, etc) compromising the use of conventional video. In addition, in order to better understand biomechanical regulations, there is a need for continuous monitoring of stroke parameters all along the race. Using IMU sensors combined with AI algorithm automatically computing biomechanical metrics cycle-to-cycle, we identified stroke regulation profiles and tipping-points in stroke regulation timing during international open water races according to performance level [10].

This research is integrated into the French national research agency program "Sport de Très Haute Performance" aiming at optimizing performances towards the 2024 Olympic and Paralympic Games. Thus, beyond scientific contributions, the solution developed is routinely used by the French Swimmming Federation in the follow-up of high level swimmers during training and competition as it serves as decision support in the context of the preparation of athletes.

8.4.8 Evaluation and monitoring of active drag and propulsive abilities of swimmers in relation with kinematics

Participants: Nicolas Bideau *(contact)*, Guillaume Nicolas, Benoit Bideau.

The aim of this work was to provide insights into optimization of swimming technique while minimizing active drag (AD) by evaluating to what extent the swimming technique affects power production and

water resistances. An indirect assessment of AD using semi-tethered conditions has be developed by means on the velocity perturbation method (VPM). This approach was also used to investigate the associations between dryland load-velocity profiles and in-situ (swimming) load-velocity parameters [19, 18]. A method allowing the identification of an optimal subject-specific load which improves AD reliability was also developed. As the for the previous topic, this research is integrated into the French national research agency program "Sport de Très Haute Performance" aiming at optimizing performances towards the 2024 Olympic and Paralympic Games. The results led to routinely on-field evaluation for high level swimmers.

8.4.9 Dancing in virtual reality as an inclusive platform for social and physical fitness activities: a survey

Participants: Franck Multon *(contact)*, Richard Kulpa.

Virtual reality (VR) has recently seen significant development in interaction with computers and the visualization of information. More and more people are using virtual and immersive technologies in their daily lives, especially for entertainment, fitness, and socializing purposes. This paper presents a qualitative evaluation of a large sample of users using a VR platform for dancing (N=292). We studied the users' motivations, experiences, and requirements for using VR as an inclusive platform for dancing, mainly as a social or physical activity. We used an artificial intelligence platform (OpenAI) to extract categories or clusters of responses automatically. We organized the data into six user motivation categories: fun, fitness, social activity, pandemic, escape from reality, and professional activities. Our results indicate that dancing in virtual reality is a different experience than in the real world, and there is a clear distinction in the user's motivations for using VR platforms for dancing. Our survey results suggest that VR is a tool that can positively impact physical and mental well-being through dancing. These findings complement the related work, help in identifying the use cases, and can be used to assist future improvements of VR dance applications [20].

8.5 Ergonomics

Ergonomics has become an important application domain in MimeTIC: being able to capture, analyze, and model human performance at work. In this domain, key challenge consists in using limited equipment to capture the physical activity of workers in real conditions. Hence, in 2022, we have explored how simulation could help to support ergonomics in the specific case of interaction between a user and a physical system, such as a weelchair or an exoskeleton.

8.5.1 Estimation of Upper-Limb Joint Torques in Static and Dynamic Phases for Lifting Tasks

Participants: Franck Multon *(contact)*, Charles Pontonnier, Georges Dumont, Hasnaa Ouadoudi Belabzioui.

We have proposed learning architectures to emulate the inverse dynamics step in motion analysis. Indeed, the in situ motion analysis of a work situation is often based on noisy and/or incomplete motion data (video, depth camera...), requiring the development of methods robust to these uncertainties. Our study focuses on the development and evaluation on reference data (opto-electronic motion capture) of a torque estimation tool for upper limbs. The system was trained to estimate joint torques for static and dynamic one-handed load carrying tasks, based on the estimated position of the joint centers, the mass carried and the mass of the subject. The generalizability of our learning models was tested in inter-subject and inter-task scenarios. The average RMSE (N.m) and the average nRMSE (%) metrics were computed for each type of learning architecture. In a future work, we aim at emulating noisy data as an input of the problem to emulate in situ conditions and improve the robustness of the approach.[30].

8.5.2   Exoskeleton biomechanical impact assessment

Participants: Charles Pontonnier *(contact)*, Aurélie Tomezzoli.

The interaction of an exoskeleton with the worker raises many issues such as joint misalignment, force transfer, control design… To properly detect such issues is a keystone to assist the user efficiently. The prototyping of such systems is also based on the caracterization for the task to assist, therefore we developed a protocol of assessment of meat cutting tasks in biomechanical terms to develop consistent specifications with regard to the objecitves of the EXOSCARNE project. It has been published in [11]. A complementary study on the impact of the mass of the exoskeleton with regard to standardized biomechanical indicators when realizing cutting tasks has been published [23]. A last work dealing with joint capacities of human for virtual maninkins has also been published [21].

8.5.3   Stepping strategies for balance recovery in dense crowds

Participants: Charles Pontonnier *(contact)*.

This work has been mostly done in interaction with the Virtus research team [12]. Stepping strategies following external perturbations from different directions is investigated in this work. We analysed the effect of the perturbation angle as well as the level of awareness of individuals and characterised steps out of the sagittal plane between Loaded Side Steps (LSS), Unloaded Medial Steps (UMS) and Unloaded Crossover Steps (UCS). A novel experimental paradigm involving perturbations in different directions was performed on a group of 21 young adults (10 females, 11 males, 20–38 years). Participants underwent 30 randomised perturbations along 5 different angles with different levels of awareness of the upcoming perturbations (with and without wearing a sensory impairment device) for a total of 1260 recorded trials. Results showed that logistic models based on the minimal values of the Margin of Stability (MoS) or on the minimal values of the Time to boundary (Ttb) performed the best in the sagittal plane. However, their accuracy stayed above 79% regardless of the perturbation angle or level of awareness. Regarding the effect of the experimental condition, evidences of different balance recovery behaviours due to the variation of perturbation angles were exposed, but no significant effect of the level of awareness was observed. Finally, we proposed the Distance to Foot boundary (DtFb) as a relevant quantity to characterise the stepping strategies in response to perturbations out of the sagittal plane. This work has also been used to implement a recovery strategy in the control of a virtual manikin in a physics-based simulation [28].

8.5.4   Backpack carriage effect on joint torques computed from a range of models: a preliminary study

Participants: Charles Pontonnier *(contact)*, Georges Dumont, Charles Pontonnier.

In a military framework, it could be interesting to predict biomechanical quantities such as joint torques and ground reaction forces while walking and carrying heavy loads. Indeed, these quantities could help to study injuries mechanism of low back pain or stress fractures related to the mass of the soldier's equipment carried on the field, which has nearly doubled since World War I (Knapik et al. 2004). The aim of this study is thus to determine to what extent it is possible to predict the influence of different load carriage conditions, on joint moments, with a baseline kinematic acquisition combined with predicted ground reaction forces and moments (GRF&Ms) as inputs [22].

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

Cifre Moovency - Critère basé effort pour l'analyse in-situ de l'activité physique au travail : Application au port de charge bimanuel

Participants: Franck Multon *(contact)*, Georges Dumont, Charles Pontonnier, Hasnaa Ouadoudi Belabizoui.

This Cifre contract has started in January 2022 for three years and is funding the PhD thesis of Hasnaa Ouadoudi-Belabizoui. It consists in building robust AI-based methods able to emulate inverse dynamics results from noisy-incomplete data to study the physical constraints of the operators in industrial workplaces. Indeed, ergonomics of such workplaces need to be assessed at the effort level and no reliable method enables such an assessment in-situ from a motion monitoring. The thesis aims at developing neural networks able to reproduce the results of a model based inverse dynamics method and then at constructing a reliable and synthetic indicator of the forces undergone by the operator during the execution of a given task.

The Cifre contracts funds the PhD salary and 10K€ per year for the supervision and management of the PhD thesis.

Cifre InterDigitial - Deep interactive control of virtual character's motion based on separating identity, motion and style

Participants: Franck Multon *(contact)*, Adnane Boukhayma, Guillaume Loranchet.

This Cifre contract has started in November 2023 for three years and is funding the PhD thesis of Guillaume Loranchet. The aim of the project is to design stylized avatars of users in immersive environment, especially Metaverse applications.

This PhD position will focus on exploring, proposing and evaluating novel solutions to represent both body shape and movements in a compact latent representation. This representation aims at simplifying the adaptation of the shape (identity) of a user, or/and his motion, and/or the style of both his shape and motion (such as transferring the user's moving shape to a fictional character with different properties and style).

With the growing interest in persistent shared virtual worlds, such as the MetaVerse immersive social network, specific problems for character animation are raised. The objective of the PhD is to propose solutions to these problems. Indeed, in these environments, users are represented by avatars with different shapes and morphologies. Compared to the face, which has been studied for decades, there is no semantic controller for the body mesh, where one could easily change the motion type and style. The character animation platform should consequently be able to adapt the motion of the user to his/her specific shape (retargetting problem), or adapt the identity of the avatar so that the user is recognizable by his/her friends, or change the style of the motion to convey a given emotion or adapt to the expected behavior of the avatar. For example, a Hulk avatar is expected to move with a specific style, but should also mimic the characteristics of the user. Finally, the distribution of these avatar models over the network is a practical challenge due to the potential scale of the shared virtual worlds. Therefore, learning a representation that allows for efficient transmission and dynamic editing has a high practical impact.

The Cifre contracts funds the PhD salary and 15K€ per year for the supervision and management of the PhD thesis. This contract is also in collaboration with Hybrid team. The PhD has been defended in March 2022.

Cifre Technicolor - Face transformation and editing for digital visual effects in film production film production

> **Participants:**   Adnane Boukhayma *(contact)*, Kelianl Baert.

The aim of this thesis is to improve the controllability of learning-based techniques for editing photorealistic faces in video sequences, in the field of visual effects for cinema. The aim is to speed up post-production processes on faces by enabling an artist to finely control different characteristics (appearance, expression and face shape) over time: rejuvenation and aging, make-up/tattooing, strong modifications morphology (adding a 3rd eye, for example), replacing an understudy with the actor's face by the actor's face, adjustments to the actor's acting.

9.2   Bilateral grants with industry

Chaire SAFRAN-Fondation Saint Cyr: Le soldat augmenté dans l'espace numérique de bataille

> **Participants:**   Charles Pontonnier *(contact)*, Georges Dumont, Aurélien Schuster.

Led by Laurent Maheo (Full Professor, Ecoles de Saint-Cyr Coëtquidan). The Chair will focus on technical innovations at the level of the Félin infantry platoon. Research activities will focus on the human element, with the aim of improving the conditions under which infantrymen evolve in their environment, and addressing the following areas: protection of the soldier and his equipment, perception of the wealth of information coming back from sensors, collaborative data sharing, for which radio communications are a central issue, reducing cognitive load and strain, and increasing mobility. It involves a dozen research professors at the Saint-Cyr Coëtquidan schools. We take part in the Chair as a experts in physical activity analysis, and propose a research theme based on physical activity assistance (load-bearing assistance, mobility assistance). The Chair has been extended over the period 2023-2028, and our work has been extended by a new sponsorship thesis (Aurélien Schuster) on the energetic optimization of load-bearing through musculoskeletal modeling.

Swim power project

> **Participants:**   Nicolas Bideau *(contact)*, Guillaume Nicolas, Benoit Bideau, Yannis Raineteau.

The Swim Power project aims at evaluating the transfer of dryland strength and conditioning programs to optimize sprint swimming performance and should also provide new practical knowledge concerning improvements in the quality of this transfer. This grant (50% EUR Digisport, 50% French Swimming Federation) served to fund the PhD of Yannis Raineteau started in 2022.

SWIMO^{2p} project

> **Participants:**   Nicolas Bideau *(contact)*, Benoit Bideau, Antoine Bouvet.

The aim of SWIMO^{2p} is to develop a mono-sensor Inertial Measurement Unit (IMU) based tool for chronic monitoring of performance variables draw on human activity recognition (HAR) during swimming by neural network model. This grant (CDSN ENS Rennes) served to fund the PhD of Antoine Bouvet started in 2022.

10 Partnerships and cooperations

10.1 European initiatives

10.1.1 Horizon Europe

SHARESPACE

Participants:	Franck Multon *(contact)*, Richard Kulpa, Benoit Bideau, Anthony Sorel, Valentin Ramel, Julian Joseph.

SHARESPACE project on cordis.europa.eu

Title: Embodied Social Experiences in Hybrid Shared Spaces

Duration: From January 1, 2023 to December 31, 2025

Partners:

- INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE (INRIA), France
- ARS ELECTRONICA LINZ GMBH, Austria
- ALE INTERNATIONAL, France
- UNIVERSITAT JAUME I DE CASTELLON (UJI), Spain
- CRDC NUOVE TECNOLOGIE PER LE ATTIVITA PRODUTTIVE SCARL (CRDC TECNOLOGIE SCARL), Italy
- RICOH INTERNATIONAL BV, Netherlands
- UNIVERSITE DE MONTPELLIER (UNIVERSITE DE MONTPELLIER), France
- GOLAEM SA (GOLAEM), France
- DE MONTFORT UNIVERSITY (DMU), United Kingdom
- DEUTSCHES FORSCHUNGSZENTRUM FUR KUNSTLICHE INTELLIGENZ GMBH (DFKI), Germany
- INSTITUT MINES-TELECOM, France
- UNIVERSITE RENNES II (RENNES 2), France
- UNIVERSITAETSKLINIKUM HAMBURG-EPPENDORF (UKE), Germany
- CYENS CENTRE OF EXCELLENCE (CYENS CoE), Cyprus
- SIA LIGHTSPACE TECHNOLOGIES, Latvia
- FUNDACIO HOSPITAL UNIVERSITARI VALL D'HEBRON - INSTITUT DE RECERCA (VHIR), Spain

Inria contact: Franck Multon

Coordinator:

Summary: SHARESHARESPACE will demonstrate a radically new technology for promoting ethical and social interaction in eXtended Reality (XR) Shared Hybrid Spaces (SHS), anchored in human sensorimotor communication. Our core concept is to identify and segment social sensorimotor primitives and reconstruct them in hybrid settings to build continuous, embodied, and rich human-avatar experiences. To achieve this, three interconnected science-towards-technology breakthroughs will be delivered: novel computational cognitive architectures, a unique self-calibrating body sensor network, and a fully mobile spatial Augmented Reality (AR) and virtual human rendering. We will create a library of social motion primitives and use them to design AI-based architectures of our

artificial agents. SHARESPACE mobile capturing technologies combine loosely-coupled visual-inertial tracking of full body kinematic, hand pose and facial expression, incorporating novel neural encoding/decoding functionalities, together with local context-aware animations and highly realistic neural rendering. Our technology will be iteratively tested in 2 Proofs-of-principles involving human and artificial agents interacting in SHS, and 3 real-world use case scenarios in Health, Sport and Art. We will demonstrate a fully functional prototype of SHARESPACE tailored to the agents' personalized characteristics (gender, culture, and social dispositions). SHARESPACE will support community-building and exploitation with concrete initiatives, including (i) public engagement around our research and innovation, (ii) promoting high-tech innovation and early transfer to our deep-tech companies, as premises for the consolidation of human-centric and sovereign European market areas such Industry AR and SHS, eHealth and tele-Health. Our long-term vision is to bring XR to a radically new level of presence and sociality by reconstructing sensorimotor primitives that enable ethical, trusted and inclusive modes of social interaction.

10.2   National initiatives

ANR HoBiS

> **Participants:** Franck Multon *(contact)*, Armel Cretual, Georges Dumont, Charles Pontonnier, Anthony Sorel, Benjamin Gamblin, Nils Hareng.

Hobis is a 42-month ANR collaborative (PRCI) project (2018-2022) entitled Hominin BipedalismS: Exploration of bipedal gaits in Hominins thanks to Specimen-Specific Functional Morphology. HoBis is leaded by the Museum Nationale d'Histoires Naturelles (CNRS), with CNRS/LAAS, and Antwerpen University (Belgium), with a total of 541KE budget (140KE for MimeTIC). HoBiS (Hominin BipedalismS) is a pluridisciplinary research project, fundamental in nature and centred on palaeoanthropological questions related to habitual bipedalism, one of the most striking features of the human lineage. Recent discoveries (up to 7 My) highlight an unexpected diversity of locomotor anatomies in Hominins that lead palaeoanthropologists to hypothesize that habitual bipedal locomotion took distinct shapes through our phylogenetic history. In early Hominins, this diversity could reveal a high degree of locomotor plasticity which favoured their evolutionary success in the changing environments of the late Miocene and Pliocene. Furthermore, one can hypothesize based on biomechanical theory that differences in gait characteristics, even slight, have impacted the energy balance of hominin species and thus their evolutionary success. However, given the fragmented nature of fossil specimens , previous morphometric and anatomo-functional approaches developed by biologists and palaeoanthropologists, do not allow the assessment of the biomechanical and energetic impacts of such subtle morphological differences, and the manners in which hominin species walked still remains unknown. To tackle this problem, HoBiS proposes as main objective a totally new specimen- specific approach in evolutionary anthropology named Specimen-Specific Functional Morphology: in- ferring plausible complete locomotor anatomies based on fossil remains, to link these reconstructed anatomies and corresponding musculoskeletal models (MSM) with plausible gaits using simulations. Both sub-objectives will make use of an extensive comparative anatomical and gait biomechanical data bases (challenges). To this end, we will integrate anatomical and functional studies, tools for anatomical modelling, optimization and simulation rooted in informatics, biomechanics, and robotics, to build an in-silico decision-support system (DSS). This DSS will provide biomechanical simulations and energetic estimations of the most plausible bipedal gaits for a variety of hominin species based on available re- mains, from partial to well-preserved specimens. MimeTIC is Leader of WP3 "Biomechanical simulation", aiming at predicting plausible bipedal lo- comotion based on paleoanthropological heuristics and a given MSM.

ANR CAPACITIES

> **Participants:** Pontonnier Charles *(contact)*, Rouvier Théo.

CAPACITIES is a 48-month ANR project (2020-2024) This project is led by Christophe Sauret, from INI/CERAH. The objective here is to build a series of biomechanical indices characterizing the biomechanical difficulty for a wide range of urban environmental situations. These indices will rely on different biomechanical parameters such as proximity to joint limits, forces applied on the handrims, mechanical work, muscle and articular stresses, etc. The definition of a more comprehensive index, called Comprehensive BioMechanical (CBM) cost, including several of the previous indices, will also be a challenging objective. The results of this project would then be used in the first place in VALMOBILE application to assist MWC users in selecting optimal route in Valenciennes agglomeration (project founded by the French National Agency for Urban Renewal and the North Department of France). The MimeTIC team is involved on the musculoskeletal simulation issues and the biomechanical costs definition. The funding for the team is about 80kE.

PIA PPR Sport REVEA

Participants: Richard Kulpa *(contact)*, Benoit Bideau, Franck Multon.

The REVEA project proposes a new generation of innovative and complementary training methods and tools to increase the number of medals at the Paris 2024 Olympic Games, using virtual reality. Indeed, the latter offers standardization, reproducibility and control features that: 1) Densify and vary training for very high performance without increasing the associated physical loads, and by reducing the risk of impact and/or high intensity exercises ; 2) offer injured athletes the opportunity to continue training during their recovery period, or for all athletes during periods of confinement as experienced with Covid-19 ; 3) provide objective and quantified assessment of athlete performance and progress; and 4) provide a wide range of training that allows for better retention of learning and adaptability of athletes. Virtual reality offers a range of stimuli that go beyond the limits of reality, such as facing an opponent with extraordinary abilities or seeing an action that has not yet been mastered. The objective of REVEA is therefore to meet the needs of three federations by exploiting the unique properties of virtual reality to improve the motor performance of athletes through the optimisation of the underlying perceptual-motor and cognitive-motor processes. The French Gymnastics Federation wishes to optimise the movements of its gymnasts by observing their own motor production to avoid further increasing the load of physical training. The French Boxing Federation wishes to improve the perceptual-motor anticipation capacities of boxers in opposition situations while reducing the impact and therefore the risk of injury. The French Athletics Federation wishes to improve the perceptual-motor anticipation capacities of athletes in cooperative situations (4x100m relay) without running at high intensity. It is performed by a multidisciplinary consortium composed of University Rennes 2 (and Inria), University of Reims Champagne-Ardenne, Aix-Marseille University, Paris-Saclay University and INSEP.

PIA PPR Sport BEST Tennis

Participants: Benoit Bideau *(contact)*, Simon Ozan.

BEST-TENNIS aims to optimize the performance of the service and return of service of the French Tennis Federation players (able-bodied and wheelchair) in the form of a systemic approach, capitalizing on biomechanical, clinical and cognitive data made available to coaches and athletes through dedicated tools. With its nine events at the Olympic and Paralympic Games, tennis is a sport with a high medal potential.

BEST-TENNIS is funded by the PIA3 PPR "Sport Haute Performance" call. This national project is leaded by researchers in MimeTIC.

PIA PPR Sport Neptune

> **Participants:** Nicolas Bideau *(contact)*, Benoit Bideau, Guillaume Nicolas.

Swimming is a sport with a high medal potential at the Olympic and Paralympic Games. Winning can be decided in 1/100s: every detail of the performance must be evaluated with precision. This is the ambition of the NePTUNE project, with the support of the French Swimming Federation (FFN) and the Handisport Federation (FFH).

To meet the needs of these sports federations, the NePTUNE project focuses on three areas of work, in order to develop innovative methods and tools for coaches to monitor swimmers. A more advanced version on human movement and energetics as well as performance optimization will also be implemented, for more elaborate scientific measurements and research.

The first axis concerns the automatic tracking and race management strategies of swimmers in competition and in training race simulations, to support the performance of medallists, detect swimmers'talents and analyze the competition. Few swimming federations around the world are involved in this type of procedure, unlike the FFN, which is innovative with its semi-automatic tracking system. However, this system needs to be improved in order to offer a fully automatic and more accurate solution.

The second axis is interested in the study of motor coordinations, propulsion and energetics to understand how the transition of behavior takes place and how the frequency/amplitude ratio as well as the underwater part of the race can be optimized. Trainers need miniature and portable sensors (such as inertial units) that automatically and quickly provide key points of swimming technique in order to maximize effectiveness, efficiency and economy.

The third axis focuses on aquatic resistances and suction effect because high performance and economy are not only due to efficient propulsion but also to the minimization of passive and active resistances.

MimeTIC is partner of this PIA3 PPR Sport Haute Performance project, leaded by Université de Rouen Normandie.

PIA EUR Digidsport

> **Participants:** Richard Kulpa *(contact)*, Benoit Bideau.

DIGISPORT (Digital Sport Sciences) offers a comprehensive, hybrid graduate school encompassing the specialties in both sport and digital sciences. It provides excellence in research and teaching by serving both traditional students and industry professionals, as well as offering formal collaborations with regional research centers. DIGISPORT helps advance the use and efficacy of digital technologies in sports and exercise, impacting all stakeholders from the users, educators, clinical practitioners, managers, and actors in the socioeconomic world. From the master's to the doctoral level, the program aims to offer students in initial and continuing training an opportunity to build a study strategy suited to their professional goals and to the labor market. Students build their own learning path through a modular teaching offer, based on pedagogical innovation, hybridization of student populations and interdisciplinary projects. The high-level technological platforms are great training tools. DIGISPORT will host renowned international researchers for its teaching programs. The Rennes ecosystem is particularly well suited to host the DIGISPORT Graduate School, both in research and education and training. It incorporates world-class research units in the field of sport (top 300 in the Shanghai ranking), digital (top 100 in the Reuters ranking of the most innovative universities in Europe and top 300 medical technologies in the Shanghai ranking) but also electronics (top 200 for the Shanghai telecommunications ranking) and human and social sciences. The research units involved in DIGISPORT are affiliated with CNRS joint labs (IRISA, IETR, IRMAR, CREST), Inria teams, Grandes Ecoles network (ENS Rennes, INSA Rennes, CentraleSupelec, ENSAI) and Université de Rennes 1 and Université Rennes 2. Rennes is also a proven socioeconomic incubator with a large network of companies organized around the Images et Réseaux cluster, French Tech-Le Poool and prominent sport institutions (CROS, Campus Sport Bretagne).

10.2.1 Défi Ys.AI

Participants: Franck Multon *(contact)*, Ludovic Hoyet, Adnane Boukhayma, Tangui Marchand Guerniou, Guillaume Loranchet.

Ys.AI is a joint project with InterDigital aiming at exploring the representation of avatars in Metaverse environments. More specifically, we aim at pushing the limits of the uncanny valley for highly realistic avatars. To this end, we explore how to enhance fullbody, garments and hair simulation using AI approaches. We also explore how these methods could enhance the interaction experience in immersive worlds, with multisensory feedback rendering.

10.2.2 PEPR eNSEMBLE

Participants: Franck Multon *(contact)*, Richard Kulpa, Ahmed Abdourahman Mahamoud.

eNSEMBLE is an ambitious national project funded by the ANR PIA4 PEPR call. The eNSEMBLE project (Future of Digital Collaboration) aims to fundamentally redefine digital tools for collaboration. Whether it is to reduce the number of people on the move, improve territorial networking, or tackle the problems and transformations of the coming decades, the challenges of the 21st century will require collaboration at an unprecedented speed and scale.

For this to happen, a paradigm shift in the design of collaborative systems is needed, comparable to the one that saw the advent of personal computing. This means inventing shared digital spaces that do more than simply replicate the physical world in virtual environments, enabling co-located and/or geographically distributed teams to work together fluidly and efficiently.

In this context, MimeTIC is involved in the PhD thesis of Ahmed Abdourahman Mahamoud. The PhD topic consists in designing an AI-based controller of autonomous virtual humans that are supposed to behave as real human would do when interacting with users. More specifically, we explore imitation learning methods to train a controller to imitate the behavior of real humans in complex interaction tasks.

10.2.3 ADT PyToM

Participants: Charles Pontonnier *(contact)*, Laurent Guillo, Georges Dumont, Salomé Ribault.

This project (2021-2023), funded by inria, aims at developing a Python version of our musculoskeletal library called CusToM and currently developed in Matlab. The project is also developing additional motion data entries (vision, depth cameras) in the library to enhance the usability of the analysis tools.

10.3 Regional initiatives

10.3.1 Croisement de filières EXOSCARNE

Participants: Charles Pontonnier *(contact)*, Aurélie Tomezzoli.

This project (2020-2023), funded by the Brittany region and endorsed by both competitive pools Valorial and EMC2, aim at designing, prototyping and commercialing a wrist exoskeleton able to help industrial butchers in their cutting and deboning tasks. It is a partnership between a R&D company called Lab4i, the mimetic team and the industrial butchery cooperl. Our role in the consortium is the development of a virtual prototyping tool based on musculoskeletal modeling to simulate the action of the exoskeleton on the wrist, and to characterize the impact of the real prototype on the action of the user thanks to full

scale experimentations involving motion, force and muscle activity sensing. The project funding is about 130kE for the team.

11   Dissemination

11.1   Promoting scientific activities

11.1.1   Scientific events: organisation

Franck Multon

Member of the organizing committees

- Franck Multon was part of the organizing committee of ECSS (European College of Science Science) annual meeting in Paris, leaded by INSEP, July 2023.

11.1.2   Scientific events: selection

Adnane Boukhayma Georges Dumont Franck Multon Charles Pontonnier

Member of the conference program committees

- Franck Multon is member of the international program committee of ACM MIG'2023, CASA2023

- Charles Pontonnier is member of the scientific comitee of the Congrès de la Société de Biomécanique 2023

Reviewer

- Franck Multon was reviewer for ACM SIGGRAPH'2023

- Charles Pontonnier was reviewer for the Congrès de la Société de Biomécanique 2023, IROS 2023

- Georges Dumont was reviewer for the Congrès de la Société de Biomécanique 2023

- Adnane Boukhayma was reviewer for CVPR 2023, ICCV 2023, NeurIPS 2023, 3DV 2023.

11.1.3   Journal

Franck Multon Charles Pontonnier

Member of the editorial boards

- Franck Multon is associated editor of the journal Computer Animation and Virtual Worlds (Wiley)

- Franck Multon is associated editor of the Journal Presence (MIT Press)

Reviewer - reviewing activities

- Franck Multon: Frontiers in Virtual Reality, Applied Sciences, Journal of NeuroEngineering and Rehabilitation, MDPI Bioengineering

- Charles Pontonnier: Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, Multibody System Dynamics, Journal of NeuroEngineering and Rehabilitation

11.1.4   Invited talks

Richard Kulpa Charles Pontonnier

- Charles Pontonnier:

  – at INRS (Nancy, January 2023): "L'analyse musculo-squelettique pour la spécification et le prototypage des systèmes d'assistance au travail"

  – Sciences 2024 summer school (Dinard, June 2023) : « Analyse musculo-squelettique et modélisation musculaire»

  – Journées Nationales de la Robotique humanoïde (JNRH) 2023 (Bordeaux, July 2023) : « Muscle modeling: a short introduction »

  – Institut de Physique de Rennes (IPR) Seminars (Rennes, september 2023) : « Caractérisation de l'interaction athlète-matériel : de l'estimation des efforts d'interaction à l'analyse énergétique »

  – Richard Kulpa: Invited symposium at ECSS (European College of Science Science) in July 2023

11.1.5   Research administration

Benoit Bideau Armel Cretual Georges Dumont Richard Kulpa Franck Multon

- Franck Multon is responsible for the coordination of national Inria actions in Sports

- Franck Multon is the scientific representative of Inria in Sciences2024 group and scientific Committee

- Franck Multon is the scientific representative of Inria in the EUR Digisport steering committe and scientific committee

- Franck Multon is the co-director of the "Nemo.AI" joint Lab with InterDigital, and the associated Défi Ys.AI

- Franck Multon is member of the Brittany commission of deontology

- Armel Crétual is the elected head of the Sports Sciences departement (STAPS) in University Rennes2

- Benoit Bideau is the head of the M2S Laboratory

- Benoit Bideau is the leader of the EUR DIGISPORT project

- Charles Pontonnier is member of the EUR digisport pedagogical comitee

- Richard Kulpa is the co-leader of the EUR DIGISPORT project

- Richard Kulpa is the scientific head of the EUR DIGISPORT project

- Georges Dumont is part of EQUIPEX+ Continuum Project, head of this project for the four involved institutions from Rennes (ENS Rennes, INSA Rennes, University of Rennes, University of Rennes 2), co-leader of the scientific committee and of the executive committee

- Georges Dumont is member of the scientific commitee of EUR DIGISPORT project

11.2   Teaching - Supervision - Juries

- Master : Franck Multon, co-leader of the IEAP Master (1 and 2) "Ingénierie et Ergonomie de l'Activité Physique", STAPS, University Rennes2, France

- Master : Franck Multon, "Santé et Performance au Travail : étude de cas", leader of the module, 30H, Master 1 M2S, University Rennes2, France

- Master : Franck Multon, "Analyse Biomécanique de la Performance Motrice", leader of the module, 30H, Master 1 M2S, University Rennes2, France

- Master: Charles Pontonnier, leader of the first year of master "Ingénierie des systèmes complexes", mechatronics, Ecole normale supérieure de Rennes, France

- Master: Charles Pontonnier, "Lagrangian Mechanics", leader of the module, 16H, M2 Complex Systems Engineering, Ecole Normale Supérieure de Rennes, France

- Master: Charles Pontonnier, Research projects, 20H, M2 SIVOS, Ecole Normale Supérieure de Rennes, France

- Master: Charles Pontonnier, "Biomechanics Modeling", 15h, Ecole Normale Supérieure de Rennes, France

- Master: Charles Pontonnier, "Human-system Cosimulation", 20h, M2 SIVOS, Ecole Normale Supérieure de Rennes, France

- Master: Charles Pontonnier, "Mechatronic assistive devices", M2 SIVOS, 15h, Ecole Normale Supérieure de Rennes, France

- Master : Georges Dumont, Responsible of the second year of the master Engineering of complex systems, École Normale Supérieure de Rennes and Rennes 1 University, France

- Master : Georges Dumont, Mechanical simulation in Virtual reality, 28H, Master Engineering of complex systems and Mechatronics, Rennes 1 University and École Normale Supérieure de Rennes, France

- Master : Georges Dumont, Mechanics of deformable systems, 40H, Master, École Normale Supérieure de Rennes, France

- Master : Georges Dumont, oral preparation to agregation competitive exam, 20H, Master, École Normale Supérieure de Rennes, France

- Master : Georges Dumont, Vibrations in Mechanics, 10H, Master, École Normale Supérieure de Rennes, France

- Master : Georges Dumont, Finite Element method, 12H, Master, École Normale Supérieure de Rennes, France

- Master: Fabrice Lamarche, "Compilation pour l'image numérique", 29h, Master 1, ESIR, University of Rennes 1, France

- Master: Fabrice Lamarche, "Synthèse d'images", 12h, Master 1, ESIR, University of Rennes 1, France

- Master: Fabrice Lamarche, "Synthèse d'images avancée", 28h, Master 1, ESIR, University of Rennes 1, France

- Master: Fabrice Lamarche, "Modélisation Animation Rendu", 36h, Master 2, ISTIC, University of Rennes 1, France

- Master: Fabrice Lamarche, "Jeux vidéo", 26h, Master 2, ESIR, University of Rennes 1, France

- Master: Fabrice Lamarche, "Motion for Animation and Robotics", 9h, Master 2 SIF, ISTIC, University of Rennes 1, France.

- Master : Armel Crétual, "Méthodologie", leader of the module, 20H, Master 1 M2S, University Rennes2, France

- Master : Armel Crétual, "Biostatstiques", leader of the module, 30H, Master 2 M2S, University Rennes2, France

- Master : Richard Kulpa, "Boucle analyse-modélisation-simulation du mouvement", 27h, leader of the module, Master 2, Université Rennes 2, France

- Master : Richard Kulpa, "Méthodes numériques d'analyse du geste", 27h, leader of the module, Master 2, Université Rennes 2, France

- Master : Richard Kulpa, "Cinématique inverse", 3h, leader of the module, Master 2, Université Rennes 2, France

- Licence : Franck Multon, "Ergonomie du poste de travail", Licence STAPS L2 & L3, University Rennes2, France

- Licence: Fabrice Lamarche, "Initiation à l'algorithmique et à la programmation", 56h, License 3, ESIR, University of Rennes 1, France

- License: Fabrice Lamarche, "Programmation en C++", 46h, License 3, ESIR, University of Rennes 1, France

- Licence: Fabrice Lamarche, "IMA", 24h, License 3, ENS Rennes, ISTIC, University of Rennes 1, France

- Licence : Armel Crétual, "Analyse cinématique du mouvement", 100H, Licence 1, University Rennes 2, France

- Licence : Richard Kulpa, "Biomécanique (dynamique en translation et rotation)", 48h, Licence 2, Université Rennes 2, France

- Licence : Richard Kulpa, "Méthodes numériques d'analyse du geste", 48h, Licence 3, Université Rennes 2, France

- Licence : Richard Kulpa, "Statistiques et informatique", 15h, Licence 3, Université Rennes 2, France

11.2.1 Supervision

- PhD in progress (beginning May 2023): Amine Ouasfi: Self-supervised learning for implicit shape reconstruction. Adnane Boukhayma, Eric Marchand.

- PhD in progress (beginning November 2023): Antoine Dumoulin: Video-based dynamic garment representation and synthesis. Adnane Boukhayma, Pierre Hellier, stefanie wuhrer, Bharath Damodaran.

- PhD in progress (beginning August 2023): Kelian Baert: Transforming and editing faces for digital visual effects in film production. Adnane BOUKHAYMA, François BODIN, Marc CHRISTIE, Benoit MAUJEAN, Fabien CASTAN.

- PhD in progress (beginning December 2020): Mohamed Younes, Learning and simulating strategies in sports for VR training, University Rennes1, Franck Multon, Richard Kulpa, Ewa Kijak, Simon Malinowski

- PhD defended on December 2023 (beginning Sep 2018): Carole Puil, Impact d'une stimulation plantaire orthétique sur la posture d'individus sains et posturalement déficients au cours de la station debout, et lors de la marche, Armel Crétual, Anne-Hélène Olivier

- PhD defended on June 21, 2023: Annabelle Limballe, Anticipation dans les sports de combat : la réalité virtuelle comme solution innovante d'entraînement, Sep. 2019, Richard Kulpa & Simon Bennett & Benoit Bideau

- PhD defended on April 17, 2023: Alexandre Vu, Evaluation de l'influence des feedbacks sur la capacité d'apprentissage dans le cadre d'interactions complexes entre joueurs et influence de ces feedbacks en fonction de l'activité sportive , Sep. 2019, Richard Kulpa & Benoit Bideau & Anthony Sorel

- PhD defended on December 15, 2023: William Mocaer, Réseaux de Neurones à Convolution Spatio-Temporelle pour l'analyse et la reconnaissance précoce d'actions et de gestes, Sep. 2019, Eric Anquetil & Richard Kulpa

- PhD in progress (beginning January 2022): Hasnaa Ouadoudi Belabzioui, Effort-based criterion for in-situ analysis of physical activity at work: application to load carrying, Charles Pontonnier, Franck Multon, Georges Dumont, Pierre Plantard (Moovency).

- PhD defended on June 2023 (beginning September 2020): Pauline Morin, Adaptation des méthodes prédiction des efforts d'interaction pour l'analyse biomécanique du mouvement en milieu écologique, Ecole normale supérieure de Rennes, direction Georges Dumont et Charles Pontonnier

- PhD in progress (beginning September 2020): Agathe Bilhaut, Stratégies perceptivo-motrices durant la locomotion des patients douloureux chroniques : nouvelles méthodes d'analyse et de suivi, Armel Crétual, Anne-Hélène Olivier, Mathieu Ménard (Institut Ostéopathie Rennes, M2S)

- PhD defended in October 2023 (beginning October 2020): Qian Li, Neural novel view synthesis of dynamic people from monocular videos, Adnane Boukhayma, Franck Multon.

- PhD in progress (beginning June 2022): Shubhendu Jena, Combining implicit and explicit representations for modeling 3D Shape and appearance, Adnane Boukhayma, Franck Multon.

- PhD in progress (beginning November 2022): Sony Saint-Auret, Virtual Collaborative « Jeu de Paume », Ronan Gaugne, Valérie Gouranton, Franck Multon, Richard Kulpa.

- PhD in progress (beginning October 2021): Rebecca Crolan, Prediction of low back load during gymnastics landings for the prevention and follow-up of athlete injuries, Charles Pontonnier, Diane Haering, Matthieu Ménard (M2S Lab).

- PhD in progress (beginning November 2022): Etienne Ricard, Musculoskeletal modeling of the "human-exoskeleton" system, Charles Pontonnier, Chris Hayot, Kevin Desbrosses (INRS).

- PhD in progress (beginning November 2023): Guillaume Loranchet, Deep interactive control of virtual character's motion based on separating identity, motion and style, Franck Multon, Adnane Boukhayma, Pierre Hellier, François Shnitzler (InterDigital).

- PhD in progress (beginning December 2023): Ahmed Abdourahman Mahamoud, MAIIL - AI-driven character simulation based on Multi-Agents Interaction Imitation Learning, Franck Multon, Richard Kulpa, Ewa Kijak and Simon Malinowski (LinkMedia team).

- PhD in progress (beginning May 2023): Valentin Ramel, Perception-Action Dynamics and synchronization in extented Reality Poloton cycling, Richard Kulpa, Benoit Bardy (Univ. Montpellier).

- PhD in progress (beginning October 2023): Aurélien, Schuster, Musculoskeletal model of the infantryman: towards an energetic analysis of physical activity on mission for equipment and load optimization, Georges Dumont, Charles Pontonnier.

- PhD in progress (beginning october 2023) : Victor Restrat, Saut à la perche, analyse générique du mouvement humain et des techniques d'interaction (PAOLI: Pole Vault generic analysis, human motion and optimal interaction), Ecole normale supérieure, Georges Dumont, Nicolas Bideau, Guillaume Nicolas

11.2.2 Juries

Franck Multon Charles Pontonnier Richard Kulpa

- PhD defense: Univ. Rennes, Brandon Le Bon, "Apprentissage profond pour l'acquisition et la restauration de champs de lumière" november 2023, Franck Multon, president

- PhD defense: Institut Polytechnique de Paris, Eduardo Alvarado, "Efficient Models for Human Locomotion and Interaction in Natural Environments", December 2023, Franck Multon, Reviewer

- HDR defense: Université de Lyon, Nicolas Pronost, "Contrôle de mouvement pour la simulation d'humains virtuels anatomiques", February 2023, Franck Multon, Reviewer

- PhD defense: ENS Rennes, Damien Hoaeau, "Optimisation du positionnement de capteurs et de récupérateurs d'énergie pour la conception de systèmes portables de reconnaissance d'activité physique, July 2023, Charles Pontonnier, Invited member

- PhD defense: ENSAM ParisTech, Guillaume Rebeyrat, "Modélisation musculosquelettique personnalisée de la marche normale et altérée pour l'aide à la prise en charge thérapeutique : application aux déformations rachidiennes de l'adulte", September 2023, Charles Pontonnier, Reviewer

- PhD defense: Université Claude Bernard Lyon 1, Sacha Guitteny, "Etude biomécanique des mécanismes de déchargement articulaire d'une orthèse de genou pour le traitement de l'arthrose", October 2023, Charles Pontonnier, Reviewer

- PhD defense: ENSAM ParisTech, Camille Eyssartier, "Analyse de la biomécanique du rachis lombaire lors de mouvements gymniques et quotidiens et effet d'un entraînement postural et musculaire", December 2023, Charles Pontonnier, Reviewer

- PhD defense: Université Rennes 2, Carole Puil, "Impact d'une stimulation plantaire orthétique sur la posture d'individus sains et posturalement déficients au cours de la station debout, et lors de la marche", Richard Kulpa, president

- PhD defense: Université Grenoble Alpes, David Pagnon, "Design and evaluation of a biomechanically consistent method for markerless kinematic analysis of sports motion", Richard Kulpa, Rapporteur

11.3 Popularization

11.3.1 Internal or external Inria responsibilities

- Franck Multon is national coordinator of the action "SportInria" in Inria

11.3.2 Education

- Franck Multon participated in writing the proposal of "TIPE (Travaux d'initiative personnelle encadrés)" subjects for the national "classes prépa" in France, on the topic « Jeu, sport ».

11.3.3 Interventions

- Franck Multon participated in Vivatech by animating a booth, Paris, May 22-25

- Franck Multon participated in the "Fête de la Science" event in Paris, by animating a booth and giving a talk to "Esprit Sorcier" TV show, Paris, October 6-7.

- Franck Multon participated in the "Fête de la Science" event in Rennes, by animating a booth, October 13-15

- Franck Multon participated in the round table organized by ScPo x Centrale Lille, entitled "L'introduction de nouvelles technologies dans le cadre des entraînements", December 2023

12 Scientific production

12.1 Major publications

[1] A. Bouvet, R. Pla, E. Delhaye, G. Nicolas and N. Bideau. 'Profiles of stroke regulations discriminate between finishing positions during international open water races'. In: *Journal of Sports Sciences* 41.13 (2023), pp. 1309–1316. DOI: 10.1080/02640414.2023.2268902. URL: https://hal.scien ce/hal-04273999.

[2] D. S. Chander, A. Tomezzoli, M. P. Cavatorta, M. Gréau, S. Marie and C. Pontonnier. 'Biomechanical requirements of meat cutting tasks: a pilot study quantifying tasks sustainability and assistance required at the wrist'. In: *Applied Ergonomics* 116 (2023), pp. 1–41. DOI: 10.1016/j.apergo.2023 .104186. URL: https://inria.hal.science/hal-04272926.

[3] L. Demestre, S. Grange, C. Dubois, N. Bideau, G. Nicolas, C. Pontonnier and G. Dumont. 'Characterization of the dynamic behavior of a diving board using motion capture data'. In: *Sports Engineering* (2022), pp. 1–18. URL: https://hal.inria.fr/hal-03788858.

[4] A. Limballe, R. Kulpa and S. Bennett. 'Using Blur for Perceptual Investigation and Training in Sport? A Clear Picture of the Evidence and Implications for Future Research'. In: *Frontiers in Psychology* 12 (2nd Mar. 2022). DOI: 10.3389/fpsyg.2021.752582. URL: https://hal.inria.fr/hal-03 656204.

[5] P. Morin, A. Muller, G. Dumont and C. Pontonnier. 'Comparison of two contact detection methods for ground reaction forces and moment estimation during sidestep cuts, runs and walks'. In: *Journal of Biomechanical Engineering* (2023), pp. 1–9. URL: https://inria.hal.science/hal-042561 86.

[6] N. Olivier, G. Kerbiriou, F. Argelaguet Sanz, Q. Avril, F. Danieau, P. Guillotel, L. Hoyet and F. Multon. 'Study on Automatic 3D Facial Caricaturization: From Rules to Deep Learning'. In: *Frontiers in Virtual Reality* 2 (19th Jan. 2022), pp. 1–15. DOI: 10.3389/frvir.2021.785104. URL: https://h al.inria.fr/hal-03763591.

[7] A. Vu, A. Sorel, A. Limballe, B. Bideau and R. Kulpa. 'Multiple Players Tracking in Virtual Reality: Influence of Soccer Specific Trajectories and Relationship With Gaze Activity'. In: *Frontiers in Psychology* 13 (20th May 2022), pp. 1–14. DOI: 10.3389/fpsyg.2022.901438. URL: https://hal .inria.fr/hal-03674770.

[8] M. Younes, E. Kijak, R. Kulpa, S. Malinowski and F. Multon. 'MAAIP: Multi-Agent Adversarial Interaction Priors for imitation from fighting demonstrations for physics-based characters'. In: *Proceedings of the ACM on Computer Graphics and Interactive Techniques* 6.3 (16th Aug. 2023), pp. 1–20. DOI: 10.1145/3606926. URL: https://hal.science/hal-04136868.

12.2 Publications of the year

International journals

[9] A. Bilhaut, M. Ménard, O. Roze, A. Crétual and A.-H. Olivier. 'Locomotion behavior of chronic Non-Specific Low Back Pain (cNSLBP) participants while walking through apertures'. In: *Gait & Posture* 104 (July 2023), pp. 140–146. DOI: 10.1016/j.gaitpost.2023.06.015. URL: https://i nria.hal.science/hal-04169296.

[10] A. Bouvet, R. Pla, E. Delhaye, G. Nicolas and N. Bideau. 'Profiles of stroke regulations discriminate between finishing positions during international open water races'. In: *Journal of Sports Sciences* 41.13 (2023), pp. 1309–1316. DOI: 10.1080/02640414.2023.2268902. URL: https://hal.scien ce/hal-04273999.

[11] D. S. Chander, A. Tomezzoli, M. P. Cavatorta, M. Gréau, S. Marie and C. Pontonnier. 'Biomechanical requirements of meat cutting tasks: a pilot study quantifying tasks sustainability and assistance required at the wrist'. In: *Applied Ergonomics* 116 (2023), pp. 1–41. DOI: 10.1016/j.apergo.2023 .104186. URL: https://inria.hal.science/hal-04272926.

[12] T. Chatagnon, A.-H. Olivier, L. Hoyet, J. Pettré and C. Pontonnier. 'Stepping Strategies of Young Adults Undergoing Sudden External Perturbation From Different Directions'. In: *Journal of Biomechanics* 157 (2023), pp. 1–12. DOI: 10.1016/j.jbiomech.2023.111703. URL: https://inria.hal.science/hal-04142469.

[13] L. Demestre, N. Bideau, G. Nicolas, C. Pontonnier and G. Dumont. 'Biomechanical analysis of the final push of an elite springboard diver'. In: *Computer Methods in Biomechanics and Biomedical Engineering* (2023). URL: https://inria.hal.science/hal-04140096.

[14] A.-R. A. Laaraibi, C. Depontailler, G. Jodin, D. Hoareau, N. Bideau and F. Razan. 'An innovative wearable sensing system based on flexible piezoresistive sensors to estimate upper body joint angle using a Nonlinear AutoRegressive exogenous Neural Model'. In: *IEEE Sensors Journal* (2nd Oct. 2023), pp. 1–12. DOI: 10.1109/jsen.2023.3319559. URL: https://hal.science/hal-04227596.

[15] A.-R. A. Laaraibi, G. Jodin, C. Depontailler, N. Bideau and F. Razan. 'Design and Characterization of Piezoresistive Sensors for Non-Planar Surfaces and Pressure Mapping: A Case Study on Kayak Paddle'. In: *Sensors* 24.1 (2023), p. 222. DOI: 10.3390/s24010222. URL: https://hal.science/hal-04368833.

[16] R. Mäkipää, R. Abramoff, B. Adamczyk, V. Baldy, C. Biryol, M. Bosela, P. Casals, J. Curiel Yuste, M. Dondini, S. Filipek, J. Garcia-Pausas, R. Gros, E. Gömöryová, S. Hashimoto, M. Hassegawa, P. Immonen, R. Laiho, H. Li, Q. Li, S. Luyssaert, C. Menival, T. Mori, K. Naudts, M. Santonja, A. Smolander, J. Toriyama, B. Tupek, X. Ubeda, P. Johannes Verkerk and A. Lehtonen. 'How does management affect soil C sequestration and greenhouse gas fluxes in boreal and temperate forests? – A review'. In: *Forest Ecology and Management* 529 (Feb. 2023), p. 120637. DOI: 10.1016/j.foreco.2022.120637. URL: https://amu.hal.science/hal-04051206.

[17] P. Morin, A. Muller, G. Dumont and C. Pontonnier. 'Comparison of two contact detection methods for ground reaction forces and moment estimation during sidestep cuts, runs and walks'. In: *Journal of Biomechanical Engineering* (2023), pp. 1–9. URL: https://inria.hal.science/hal-04256186.

[18] Y. Raineteau, G. Nicolas, B. Bideau, N. Bideau and R. Pla. 'Associations between load-velocity profiling and race parameters of elite swimmers in the 100 and 200m freestyle events'. In: *Frontiers in Sports and Active Living.* Frontiers in Sports and Active Living 5 (2023), p. 1326106. DOI: 10.3389/fspor.2023.1326106. URL: https://hal.science/hal-04357925.

[19] Y. Raineteau, R. Pla, B. Bideau, N. Bideau and G. Nicolas. 'From dry-land to the water: training and testing practices of strength and conditioning coaches in high level French sprint swimmers'. In: *Frontiers in Sports and Active Living* 5 (12th Jan. 2024), p. 1338856. DOI: 10.3389/fspor.2023.1338856. URL: https://hal.science/hal-04415386.

[20] B. Sarupuri, R. Kulpa, A. Aristidou and F. Multon. 'Dancing in virtual reality as an inclusive platform for social and physical fitness activities: a survey'. In: *The Visual Computer* (16th Aug. 2023), pp. 1–16. DOI: 10.1007/s00371-023-03068-6. URL: https://inria.hal.science/hal-04207825.

[21] J. Savin, D. Haering, N. Rezzoug and C. Pontonnier. 'Simulation of maximum isometric and isokinetic elbow actuation torques based on zonotopes'. In: *Computer Methods in Biomechanics and Biomedical Engineering* (2023), pp. 1–2. URL: https://inria.hal.science/hal-04140099.

[22] A. Schuster, A. Tomezzoli, C. Pontonnier and G. Dumont. 'Backpack carriage effect on joint torques computed from a range of models: a preliminary study'. In: *Computer Methods in Biomechanics and Biomedical Engineering* (2023). URL: https://inria.hal.science/hal-04140093.

[23] A. Tomezzoli, A. Schuster, G. Dumont and C. Pontonnier. 'Effect of mass addition on upper limb joint torques during meat cutting tasks: a parametric study'. In: *Computer Methods in Biomechanics and Biomedical Engineering* (2023), pp. 1–2. URL: https://inria.hal.science/hal-04140090.

[24] X. Wang, S. Prévost, A. Boukhayma, E. Desjardin, C. Loscos, B. Morisset and F. Multon. 'Evaluation of hybrid deep learning and optimization method for 3D human pose and shape reconstruction in simulated depth images'. In: *Computers and Graphics* 115 (2023), pp. 158–166. DOI: 10.1016/j.cag.2023.07.005. URL: https://inria.hal.science/hal-04159384.

[25] M. Younes, E. Kijak, R. Kulpa, S. Malinowski and F. Multon. 'MAAIP: Multi-Agent Adversarial Interaction Priors for imitation from fighting demonstrations for physics-based characters'. In: *Proceedings of the ACM on Computer Graphics and Interactive Techniques* 6.3 (16th Aug. 2023), pp. 1–20. DOI: 10.1145/3606926. URL: https://hal.science/hal-04136868.

International peer-reviewed conferences

[26] R. Gaugne, S. Saint-Auret, P. Duc-Martin and V. Gouranton. 'Virtual Reality for the Preservation and Promotion of Historical Real Tennis'. In: *Proceedings of Computer Graphics International*. CGI 2023 - Computer Graphics International. Shangai, China, 2023, pp. 1–13. URL: https://hal.science/hal-04211663.

[27] S. Jena, F. Multon and A. Boukhayma. 'Neural Mesh-Based Graphics'. In: ECCV 2022 Workshops. Lecture Notes in Computer Science. Tel-Aviv, Israel, 16th Jan. 2023, pp. 739–757. DOI: 10.1007/978-3-031-25066-8_45. URL: https://inria.hal.science/hal-03942106.

[28] A. Jensen, T. Chatagnon, N. Khoshsiyar, D. Reda, M. van de Panne, C. Pontonnier and J. Pettré. 'Physical Simulation of Balance Recovery after a Push'. In: MIG 2023 - 15th Annual ACM SIGGRAPH Conference on Motion, Interaction and Games. Rennes, France: ACM, 2023, pp. 1–11. DOI: 10.1145/3623264.3624448. URL: https://inria.hal.science/hal-04228033.

[29] Q. Li, F. Multon and A. Boukhayma. 'Learning Generalizable Light Field Networks from Few Images'. In: ICASSP 2023 - IEEE International Conference on Acoustics, Speech, and Signal Processing. Rhodes, Greece: IEEE, 4th June 2023, pp. 1–5. DOI: 10.1109/icassp49357.2023.10096979. URL: https://inria.hal.science/hal-04116795.

[30] H. Ouadoudi Belabzioui, C. Pontonnier, G. Dumont, P. Plantard and F. Multon. 'Estimation of Upper-Limb Joint Torques in Static and Dynamic Phases for Lifting Tasks'. In: *Lecture Notes in Networks and Systems*. DHM 2023 - 8th International Digital Human Modeling Symposium. Lecture Notes in Networks and Systems. Antwerpen, Belgium, 2023, pp. 1–10. URL: https://inria.hal.science/hal-04140086.

Conferences without proceedings

[31] A.-R. Anas, G. Jodin, M. Costanza, D. Hoareau, S. Margueron, N. Bideau and F. Razan. 'A low cost, self-powered, plantar pressure distribution sensing insole +'. In: XXXV EUROSENSORS Conference 2023. Leece, Italy, 2023, pp. 1–2. URL: https://hal.science/hal-04368830.

[32] M. Egiziano, L. Chomienne, M. Bossard, E. Verhulst, R. Kulpa, N. Mascret and G. Montagne. 'How variability could shape perceptual-motor expertise in 4x100 m relay?' In: ECSS 2023 - Annual Congress of the European College of Sport Science. Paris, France, 4th July 2023, pp. 1–1. URL: https://univ-eiffel.hal.science/hal-04199906.

[33] R. Kulpa. 'VR for training perceptual-motor skills of boxers and relay runners for Paris 2024 Olympic games'. In: ECSS 2023 - 28th Annual Congress of the European College of Sport Science. Paris, France, 2023. URL: https://inria.hal.science/hal-04219135.

[34] N. Mascret, G. Montagne, A. Devrièse-Sence and R. Kulpa. 'Acceptance by athletes of a virtual reality head-mounted display intended to enhance sport performance'. In: ECSS 2023 - European Congress of Sport Science. Paris, France, 2023. URL: https://amu.hal.science/hal-04217746.

[35] L. Stefanuto, L. Chomienne, M. Bossard, E. Verhulst, R. Kulpa, N. Mascret and G. Montagne. 'In search of the signature of perceptual-motor expertise in 4x100 m relay'. In: ECSS 2023 - Annual Congress of the European College of Sport Science. Palais des Congres, Paris, France, 4th July 2023, pp. 1–1. URL: https://univ-eiffel.hal.science/hal-04199917.

Doctoral dissertations and habilitation theses

[36] Q. Li. 'Novel view synthesis from sparse inputs'. Université de Rennes, 17th Oct. 2023. URL: https://theses.hal.science/tel-04280320.

[37]   W. Mocaër. 'Spatio-Temporal Convolutional Neural Networks for the analysis and early recognition of actions and gestures'. Institut national des sciences appliquées de Rennes, 15th Dec. 2023. URL: https://hal.science/tel-04414871.

[38]   L. Mourot. 'Deep learning for skeletal character animation : topology editing, retargeting and cleaning'. Université de Rennes, 4th May 2023. URL: https://theses.hal.science/tel-04219 725.

Other scientific publications

[39]   A. Devrièse-Sence, L. Chomienne, M. Bossard, E. Verhulst, R. Kulpa, G. Montagne and N. Mascret. 'Acceptance by coaches of immersive virtual reality for improving sport performance'. In: ECSS 2023 - 28th Annual Congress of the European College of Sport Science. Paris, France: Unpublished, 6th July 2023. DOI: 10.13140/RG.2.2.27130.06089. URL: https://hal.science/hal-042036 11.

[40]   A. Devrièse-Sence, L. Chomienne, M. Egiziano, L. Stefanuto, E. Verhulst, R. Kulpa, G. Montagne and N. Mascret. 'Acceptabilité et acceptation du casque de réalité virtuelle chez les athlètes élites en relais 4 x 100 m'. In: ACAPS 2023 - 20e congrès de l'ACAPS : Les Environnements de l'Activité Physique et Sportive. Reims, France, 31st Oct. 2023. URL: https://hal.science/hal-04273773.