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**Université Joseph Fourier
(Grenoble)**

Activity Report 2014

Project-Team IMAGINE

Intuitive Modeling and Animation for
Interactive Graphics & Narrative Environments

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Interaction and visualization

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Project-Team IMAGINE

Keywords: Computer Graphics, Geometry Modeling, Computer Animation, Interaction, Ontology Matching, Interactive Graphics

Creation of the Team: 2012 January 01, updated into Project-Team: 2013 January 01.

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2. Overall Objectives

2.1. Context

With the fast increase of computational power and of memory space, increasingly complex and detailed 3D content is expected for virtual environments. Unfortunately, 3D modeling methodologies did not evolve as fast: most users still use standard CAD or 3D modeling software (such as Maya, 3DS or Blender) to design each 3D shape, to animate them and to manually control cameras for movie production. This is highly time consuming when large amounts of detailed content need to be produced. Moreover the quality of results is fully left in the user's hand, which restricts applicability to skilled professional artists. More intuitive software such as Z-Brush are restricted to shape design and still require a few months for being mastered by sculpture practitioners. Reducing user load can be done by capturing and re-using real objects or motions, at the price of restricting the range of possible content. Lastly, procedural generation methods can be used in specific cases to automatically get some detailed, plausible content. Although they save user's time, these procedural methods typically come at the price of control: indirect parameters need to be tuned during a series of trial and errors until the desired result is reached. Stressing that even skilled digital artists tend to prefer pen and paper than 3D computerized tools during the design stages of shapes, motion, and stories, Rob Cook, vice president of technology at Pixar animation studios recently stated (key-note talk, Siggraph Asia 2009): *new grand challenge in Computer Graphics is to make tools as transparent to the artists as special effects were made transparent to the general public.*

Could digital modeling be turned into a tool, even more expressive and simpler to use than a pen, to quickly convey and refine shapes, motions and stories? This is the long term vision towards which we would like to advance.

2.2. Scientific goals

The goal of the IMAGINE project is to develop **a new generation of models, algorithms and interactive environments for the interactive creation of animated 3D content and its communication through virtual cinematography.**

Our insight is to revisit models for shapes, motion, and narration from a user-centred perspective, i.e. to give models an intuitive, predictable behaviour from the user's view-point. This will ease both semi-automatic generation of animated 3D content and fine tuning of the results. The three main fields will be addressed:

1. **Shape design:** We aim to develop intuitive tools for designing and editing 3D shapes and their assemblies, from arbitrary ones to shapes that obey application-dependent constraints - such as, for instance, developable surfaces representing cloth or paper, or shape assemblies used for CAD of mechanical prototypes.
2. **Motion synthesis:** Our goal is to ease the interactive generation and control of 3D motion and deformations, in particular by enabling intuitive, coarse to fine design of animations. The applications range from the simulation of passive objects to the control of virtual creatures.

3. **Narrative design:** The aim is to help users to express, refine and convey temporal narrations, from stories to educational or industrial scenarios. We develop both virtual direction tools such as interactive storyboarding frameworks, and high-level models for virtual cinematography, such as rule-based cameras able to automatically follow the ongoing action and automatic film editing techniques.

In addition to addressing specific needs of digital artists, this research contributes to the development of new expressive media for 3D content. The long term goal would be to enable any professional or scientist to model and interact with their object of study, to provide educators with ways to quickly express and convey their ideas, and to give the general public the ability to directly create animated 3D content.

3. Research Program

3.1. Methodology

As already stressed, thinking of future digital modeling technologies as an Expressive Virtual Pen enabling to seamlessly design, refine and convey animated 3D content, leads to revisit models for shapes, motions and stories from a user-centered perspective. More specifically, inspiring from the user-centered interfaces developed in the Human Computer Interaction domain, we introduced the new concept of user-centered graphical models. Ideally, such models should be designed to behave, under any user action, the way a human user would have predicted. In our case, user's actions may include creation gestures such as sketching to draft a shape or direct a motion, deformation gestures such as stretching a shape in space or a motion in time, or copy-paste gestures to transfer some of the features from existing models to other ones. User-centered graphical models need to incorporate knowledge in order to seamlessly generate the appropriate content from such actions. We are using the following methodology to advance towards these goals:

- Develop high-level models for shapes, motion and stories that embed the necessary knowledge to respond as expected to user actions. These models should provide the appropriate handles for conveying the user's intent while embedding procedural methods that seamlessly take care of the appropriate details and constraints.
- Combine these models with expressive design and control tools such as gesture-based control through sketching, sculpting, or acting, towards interactive environments where users can create a new virtual scene, play with it, edit or refine it, and semi-automatically convey it through a video.

3.2. Validation

Validation is a major challenge when developing digital creation tools: there is no ideal result to compare with, in contrast with more standard problems such as reconstructing existing shapes or motions. Therefore, we had to think ahead about our validation strategy: new models for geometry or animation can be validated, as usually done in Computer Graphics, by showing that they solve a problem never tackled before or that they provide a more general or more efficient solution than previous methods. The interaction methods we are developing for content creation and editing rely as much as possible on existing interaction design principles already validated withing the HCI community. We also occasionally develop new interaction tools, most often in collaboration with this community, and validate them through user studies. Lastly, we work with expert users from various application domains through our collaborations with professional artists, scientists from other domains, and industrial partners: these expert users validate the use of our new tools compared to their usual pipeline.

4. Application Domains

4.1. Domain

This research can be applied to any situation where users need to create new, imaginary, 3D content. Our work should be instrumental, in the long term, for the visual arts, from the creation of 3D films and games to the development of new digital planning tools for theatre or cinema directors. Our models can also be used in interactive prototyping environments for engineering. They can help promoting interactive digital design to scientists, as a tool to quickly express, test and refine models, as well as an efficient way for conveying them to other people. Lastly, we expect our new methodology to put digital modeling within the reach of the general public, enabling educators, media and other practitioners to author their own 3D content.

Our current application domains are:

- Visual arts
 - Modeling and animation for 3D films and games.
 - Virtual cinematography and tools for theatre directors.
- Engineering
 - Industrial design.
 - Mechanical & civil engineering.
- Natural Sciences
 - Virtual functional anatomy.
 - Virtual plants.
- Education and Creative tools
 - Sketch-based teaching.
 - Creative environments for novice users.

The diversity of users these domains bring, from digital experts to other professionals and novices, gives us excellent opportunities to validate our general methodology with different categories of users. Our ongoing projects in these various application domains are listed in Section 6.

5. New Software and Platforms

5.1. MyCorporisFabrica

Participants: Ali-Hamadi Dicko, François Faure, Olivier Palombi, Federico Ulliana.

My Corporis Fabrica (MyCF) is an anatomical knowledge ontology developed in our group. It relies on FMA (Foundational Model of Anatomy), developed under Creative Commons license (CC-by). MyCF browser is available on line, and is already in use for education and research in anatomy: <http://www.mycorporisfabrica.org/>. Moreover, the MyCf's generic programming framework can be used for other domains, since the link it provides between semantic and 3D models matches several other research applications at IMAGINE.

5.2. SOFA

Participants: François Faure, Armelle Bauer, Olivier Carré, Aurélie Dégletagne, Ali Hamadi Dicko, Matthieu Nesme, Romain Testylier.

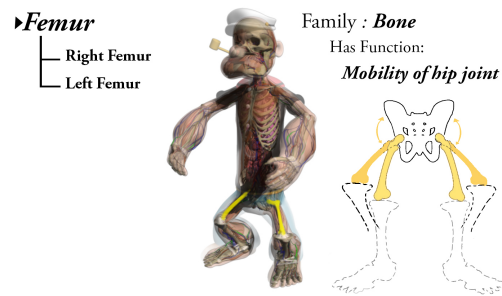


Figure 1. My Corporis Fabrica is an anatomical knowledge database developed in our team.

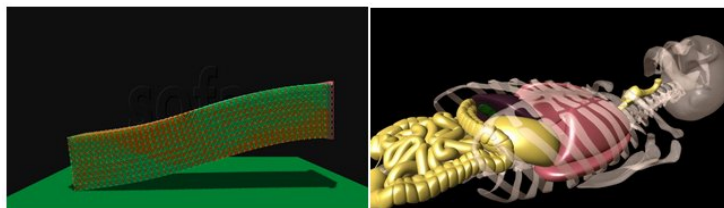


Figure 2. SOFA is an open source simulator for physically based modeling.

SOFA is a real-time physically based simulation library developed for more 8 years with other Inria research groups (Shacra and Asclepios). It primarily targeted medical simulation research, but we are using it as well for many other applications, from the entertainment industry (films and games) to earth science projects. Based on an advanced software architecture, it allows to (1) create complex and evolving simulations by combining new algorithms with algorithms already included in SOFA; (2) modify most features of the simulation (deformable behavior, surface representation, solver, constraints, collision algorithm, etc.) by simply editing an XML file; (3) build complex models from simpler ones using a scenegraph description; (4) efficiently simulate the dynamics of interacting objects using abstract equation solvers; and (5) reuse and easily compare a variety of available methods.

SOFA is gaining momentum. A start-up based on SOFA, InSimo, has been created in Strasbourg by Inria people, and one of our former engineers, François Jourdes, has been hired.

5.3. Expressive

Participants: Marie-Paule Cani, Antoine Begault, Rémi Brouet, Even Entem, Thomas Delame, Ulysse Vimont, Cédric Zanni.

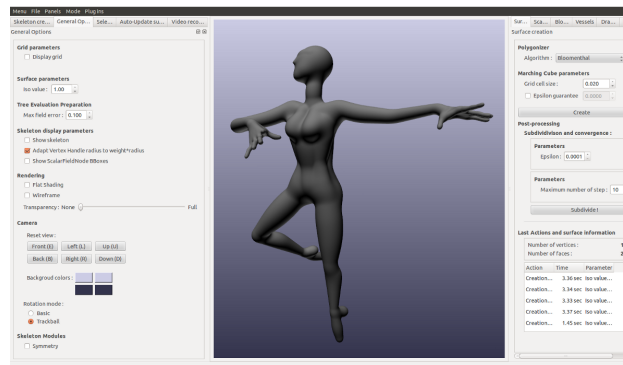


Figure 3. GUI and Example of implicit surface and modeled with the Expressive platform.

Expressive is a new C++ library created in 2013 for gathering and sharing the models and algorithms developed within the ERC Expressive project. It enables us to make our latest research results on new creative tools - such as high level models with intuitive, sketching or sculpting interfaces - soon available to the rest of the group and easily usable for our collaborators, such as Evelyne Hubert (Inria, Galaad) or Loic Barthe (IRIT, Toulouse). The most advanced part is a new version of Convol, a library dedicated to implicit modeling, with a main focus on integral surfaces along skeletons. Convol incorporates all the necessary material for constructive implicit modeling, a variety of blending operators and several methods for tessellating an implicit surface into a mesh, and for refining it in highly curved regions. The creation of new solid geometry can be performed by direct manipulation of skeletal primitives or through sketch-based modeling and multi-touch deformations.

6. New Results

6.1. Highlights of the Year

- Vector Graphics Complexes, an new structure for 2D illustration developed in collaboration with UBC, resulted into a publication at ACM SIGGRAPH [4]. This superset of multi-layers graphics and of planar maps, enable intuitive design and deformation of 2D illustrations thanks to the separation of geometry from topology.

- Our work on elastic implicit skinning, a collaboration with U. Toulouse, Victoria University, and Inria Bordeaux was accepted at ACM SIGGRAPH Asia [16]. Thanks to robust iso-surface tracking, this method captures dynamic skin sliding effects and can be used with extreme bending angles.

6.2. User-centered Models for Shapes

- **Scientist in charge:** Stefanie Hahmann.
- **Other permanent researchers:** Marie-Paule Cani, Jean-Claude Léon.

Our goal, is to develop responsive shape models, i.e. 3D models that respond in the expected way under any user action, by maintaining specific application-dependent constraints (such as a volumetric objects keeping their volume when bent, or cloth-like surfaces remaining developable during deformation, etc). We are extending this approach to composite objects made of distributions and/or combination of sub-shapes of various dimensions.

6.2.1. Implicit modeling

Participants: Antoine Bégault, Marie-Paule Cani, Michael Gleicher, Cédric Zanni.



Figure 4. Illustration from [17] showing some results of our N-ary implicit blends.

Our insight towards 3D shapes that respond in an intuitive way during both design and animation is to develop representations that clearly separate changes of structure - namely, the morphology of the shape - from changes of posture (its current 3D isometric embedding). Using skeletons is an excellent way to do so for 3D solids: the structure of a shape is represented by the topology of the skeleton, the length of its components and the shape thickness around it, while the shape posture is defined by the embedding of the skeleton in 3D space. Implicit surfaces (iso-surfaces of scalar fields) are the best mathematical model so far for generating 3D shapes from skeletons. However, a number of long standing problems - blending at distance that makes topology unpredictable, bulges at junctions, blurring of details - reduced the interest for this representation for many years. We addressed several of these issues in the last few years. Our most recent contribution is a method for enabling topology control in the case n-ary implicit blends [17]. Shapes are modeled using scale-invariant integral primitives (SCALIS) along skeletons, and blend with a plus. We use field warping to avoid unwanted blending and provide a unique control (based for instance on the angle) on the way skeleton-based primitives are allowed to blend. See Figure 4

6.2.2. Towards responsive assemblies

Participants: Stefanie Hahmann, Jean-Claude Léon, Aarohi Singh Johal.

We chose to focus on man-made objects to tackle the topic of shape assemblies, since CAD models of virtual industrial prototypes provide an excellent, real-size test-bed for our methods. Moreover, this is perfectly fitting the demand from industrial partners such as Airbus group and EDF.

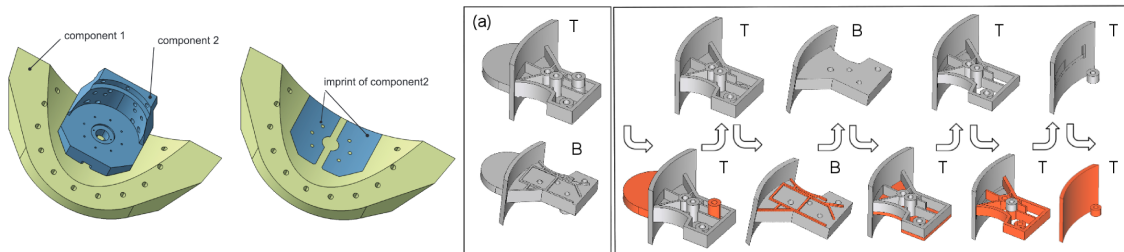


Figure 5. Illustration from [8] (Left) showing the automatic extraction of geometric interfaces, and from [2] (Right) showing the automatic generation of a construction graph.

Assemblies representing products are most often reduced to a collection of independent CAD models representing each component. The designation of each component and information about its function are often missing. As a result, geometric interfaces between components are unknown. These interfaces are particularly useful for structural mechanics to be able to quickly generate a Finite Element model of the assembly. This is especially critical when the latter gets very complex. [8] addresses the problem of automatically generating a class of geometric interfaces for very complex assemblies. GPU-based algorithms have proved suitable to obtain reliable results on CAD models.

Precisely determining interfaces between components is also a first requirement to enrich geometric models with functional information, since a subset of functions derives from interfaces between components. Based on both geometric interfaces and on a new concept of conventional interfaces, we proposed a series of approaches [13], [3] that make use of qualitative and ontology-based reasoning to connect CAD components and their geometric interfaces to functions or to functional designations of components: this results into an intrinsic identifier of a component in an assembly that connects it to its function.

To efficiently process assemblies of components, shape analysis [40] is particularly useful to generate the dimensionally reduced models needed for structural mechanics. [2] shows that analyzing a B-Rep CAD model to derive a construction graph, i.e. a set of construction trees, can be a robust basis to generate dimensionally reduced models.

Lastly, we extended shape analysis methods to detect some sets of symmetries [9]. Recovering this knowledge and embedding it into a model is the first step towards functionality-preserving deformations of complex man-made prototypes.

6.2.3. Parametric shapes

Participants: Stefanie Hahmann, Léo Allemand-Giorgis, Tibor Stanko.

We are developing new smooth parametric surface models defined on irregular quad meshes. They are in fact a powerful alternative to subdivision surface and singularly parameterized tensor product surfaces since they combine the advantages of both, the arbitrary topology of quad meshes and the smoothness of the tensor product patches. In collaboration with G.-P. Bonneau (Maverick team) several parametric triangular surface models for arbitrary topologies have been developed in the past. A new surface spline model has been published [1] and presented at GMP'14. It solves the problem of defining a G^1 -continuous surface interpolating the vertices of an arbitrary quad mesh with low degree polynomial tensor product patches. It further aims to produce shapes of very high visual quality while reducing the number of control points, see Figure 6(right).



Figure 6. Illustration from [38](Left) showing our results on monotonic interpolation, and from [1](Right) with our $G1$ interpolation surfaces for quad meshes.

Another contribution concerns the modeling and smoothing of shapes using the Morse-Smale complex. The Morse-Smale complex is a topological structure defined on scalar functions which extracts critical points of the function and the links between them. By encoding a hierarchy between critical points, less important critical points can be deleted in order to simplify the structure. Our goal is to reconstruct a new shape, which corresponds to the simplified structure while approximating the initial data and preserving the most salient features. We first developed a method for interpolating monotone increasing 2D scalar data with a monotone piecewise cubic C^1 -continuous surface. Monotonicity is a sufficient condition for a function to be free of critical points inside its domain. We overcome the restrictive standard axial monotonicity for tensor-product surfaces and introduce sufficient conditions and two algorithms for a more relaxed monotonicity constraint [38], see a piecewise monotonic shape in Figure 6(left). Then, some preliminary results on shape reconstruction from Morse-Smale complexes have been presented as a Poster and at a national conference [35].

In collaboration with Hans Hagen and Anne Berres from University of Kaiserslautern, we investigated conditions under which shape deformations preserve surface curvatures. The work has been published as a chapter in a scientific book [39].

6.3. Models for Motion Synthesis

- **Scientist in charge:** François Faure.
- **Other permanent researchers:** Marie-Paule Cani, Damien Rohmer, Rémi Ronfard.

Animating objects in real-time is mandatory to enable user interaction during motion design. Physically-based models, an excellent paradigm for generating motions that a human user would expect, tend to lack efficiency for complex shapes due to their use of low-level geometry (such as fine meshes). Our goal is therefore two-folds: first, develop efficient physically-based models and collision processing methods for arbitrary passive objects, by decoupling deformations from the possibly complex, geometric representation; second, study the combination of animation models with geometric responsive shapes, enabling the animation of complex constrained shapes in real-time. The last goal is to start developing coarse to fine animation models for virtual creatures, towards easier authoring of character animation for our work on narrative design.

6.3.1. Real-time physically-based models

Participants: Armelle Bauer, Ali Hamadi Dicko, François Faure, Matthieu Nesme.

Following the success of frame-based elastic models (Siggraph 2011), a real-time animation framework provided in SOFA and currently used in many of our applications with external partners, we further improved this year the efficiency of this approach: we developed an adaptive version of frame-based elastic models, where frames get seamlessly attached to other ones during deformations when appropriate, in order to reduce computations [14], [33].

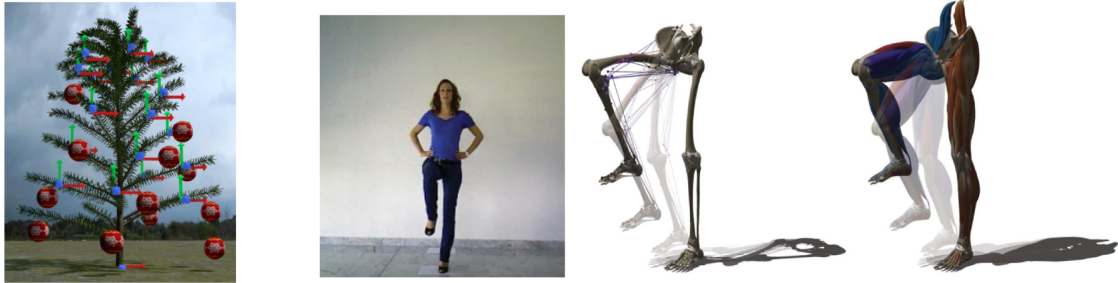


Figure 7. Illustration from [14](Left) showing our velocity based adaptive simulation, and from [21](Right) on interactive visualization of muscle activity.

Frame-based models were successfully used to model limb movements in anatomical modeling [21]. The efficiency of this method enables us to advance towards the concept of a *Living book of anatomy*, where users move their own body and observe it through a tablet to get some visual illustration of anatomy in motion (see Figure 7).

6.3.2. Specific models for virtual creatures

Participants: Marie-Paule Cani, Michael Gleicher.

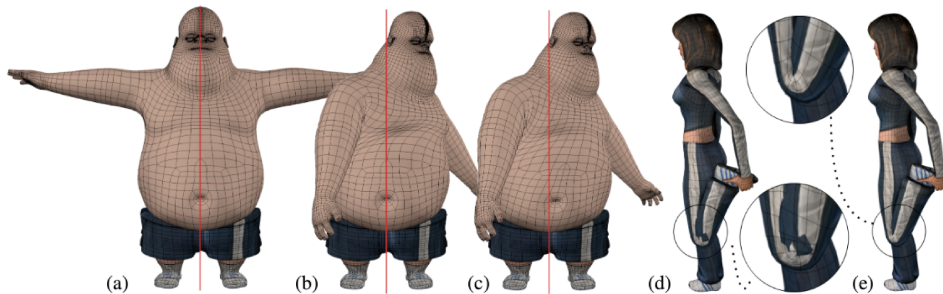


Figure 8. Illustration from [16] showing our results on dynamic skin deformations.

In collaboration with Loic Barthe and Rodolphe Vaillant from IRIT (U. Toulouse), Brian Wyvill (U. Victoria) and Gael Guennebaud (Manao, Inria), we developed a new automatic method for character skinning: Based on the approximation of character limbs with Hermite RBF implicit volumes, we adjust the mesh vertices representing the skin by projecting them back, at each animation step, to their iso-surface of interest. Since the vertices start from their previous position at the last animation step, there is no need of specifying skinning weights and using another skinning method as pre-computation, as in our previous implicit skinning method. Our solution avoids the well known blending artifacts of linear blend skinning and of dual quaternions, accommodates extreme blending angles and captures elastic effect in skin deformation [16].

This year, we also studied the way character eyes and gazes are to be animated. This extensive study resulted into a state of the art paper published at the Eurographics conference [32]

6.4. Knowledge-based Models for Narrative Design

- **Scientist in charge:** Rémi Ronfard.
- **Other permanent researchers:** Marie-Paule Cani, François Faure, Jean-Claude Léon, Olivier Palombi.

Our long term goal is to develop high-level models helping users to express and convey their own narrative content (from fiction stories to more practical educational or demonstrative scenarios). Before being able to specify the narration, a first step is to define models able to express some a priori knowledge on the background scene and on the object(s) or character(s) of interest. Our first goal is to develop 3D ontologies able to express such knowledge. The second goal is to define a representation for narration, to be used in future storyboarding frameworks and virtual direction tools. Our last goal is to develop high-level models for virtual cinematography such as rule-based cameras able to automatically follow the ongoing action and semi-automatic editing tools enabling to easily convey the narration via a movie.

6.4.1. Knowledge representation through 3D ontologies

Participants: Armelle Bauer, Jean-Claude Léon, Olivier Palombi.

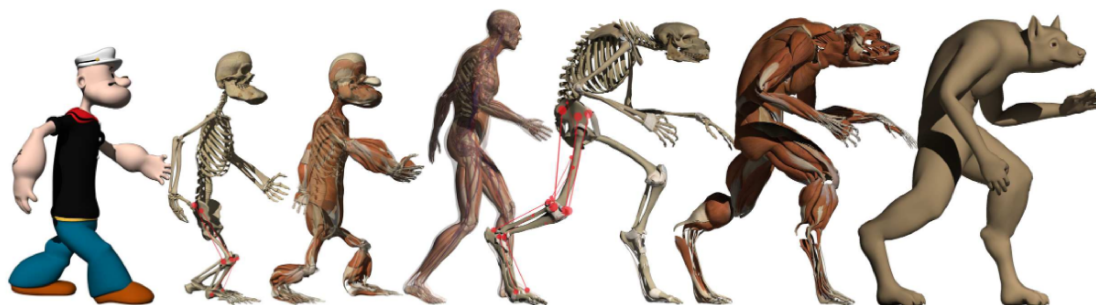


Figure 9. Illustration from [22] showing our results on ontology based anatomy generation.

We chose to develop 3D ontologies for being able to express combined knowledge on geometry, motion and function for assemblies or hierarchies of 3D objects. This is done in collaboration with a specialized group from the LIG laboratory in Grenoble. We decided to first focus these ontologies developments on two topics on which group members have a strong expertise: the anatomical domain (an interesting application test-bed for educational scenarios) and the industrial prototyping domain (where assembly scenarios can be defined).

We developed an anatomical knowledge database called My Corporis Fabrica (MyCF). We first linked functional entities defined in MyCF to the involved anatomical structures, using the musculoskeletal system as a test-bed. Based on this new formal description of the functional anatomy of limbs, we presented a novel pipeline for the construction of biomechanical simulations by combining generic anatomical knowledge with specific data which can handle complex reasoning and querying in MyCF. This resulted into a publication in the Journal of Biomedical Semantics [11]. We also used MyCF within our previous framework of anatomical transfert to set up an assistant tool for modeling and simulating anatomical structure such as bones, muscles, viscera and fat tissues easily while ensuring a correct anatomical consistency [22].

Secondly, in analysing the similarities and differences between existing ontology based description of products and virtual humans, we developed a common framework for combining 3D models and functional description to both models [15], [34].

6.4.2. Virtual direction tools

Participants: Adela Barbulescu, Rémi Ronfard.

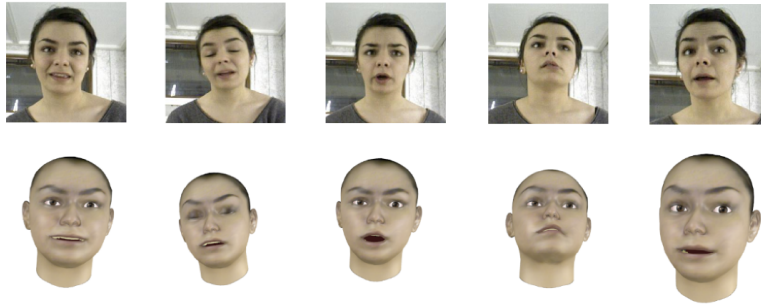


Figure 10. Illustration from [20] showing our results on expressive virtual actors.

We are developing a new approach to transfer speech signals and 3D facial expressions to virtual actors of a different identity. The converted sequences should be perceived as belonging to the target actors. This is the goal of Adela Barbulescu's thesis, co-advised by Gérard Bailly from GIPSA-lab. Our work started with conversion of speaking styles through speech signals only. This year, we started extending this approach to visual prosody and advanced on communicating social attitudes through head gestures [20].

6.4.3. Virtual cinematography

Participants: Quentin Galvane, Vineet Ghandi, Christophe Lino, Rémi Ronfard.



Figure 11. Illustration from [23] showing our results on narrative-driven camera control of computer games.

Our goal is to model automatic cameras for covering 3D scenes, as well as to develop semi-automatic film editing techniques to help conveying narration. This work was first conducted on video data, enabling us to test our ideas without the need for complex 3D movies: we designed an automatic method for the identification of actors in a video, and are using it for the automatic re-framing and editing high-resolution videos shots of theater rehearsals [25].

In parallel, we started extending this methodology to 3D animation, in collaboration with the Mimetic group in Rennes and with Geneva University: this year, we proposed a new method for replaying first person video games with automatic camera control based on the narration [23]. We also advanced towards semi-automatic film editing: A paper was just accepted to AAI 2015. To stress the difficulty of validating film editing methods, we devoted a specific work to validation methodologies [27].

We also addressed other issues related to cinematography and narratives: We designed a pre-visualization system for 3D cinematography to be used in the Action3DS project [30]: the method makes use of 3D modeling to show what the spectators watching a 3D movie are going to see, in order to ease 3D camera control by the film director. Lastly, we worked on computer generation of narrative discourses with the university of Geneva [31].

This year, Remi Ronfard and Vineet Gandhi wrote a patent application "Dispositif de génération de rushes cinématographiques par traitement vidéo", demande de brevet français no. 1460957, déposée le 13 novembre 2014.

6.5. Creating and Interacting with Virtual Prototypes

- **Scientist in charge:** Jean-Claude Léon.
- **Other permanent researchers:** Marie-Paule Cani, Olivier Palombi, Damien Rohmer, Rémi Ronfard.

The challenge is to develop more effective ways to put the user in the loop during content authoring. We generally rely on sketching techniques for quickly drafting new content, and on sculpting methods (in the sense of gesture-driven, continuous distortion) for further 3D content refinement and editing. The objective is to extend these expressive modeling techniques to general content, from complex shapes and assemblies to animated content. As a complement, we are exploring the use of various 2D or 3D input devices to ease interactive 3D content creation.

6.5.1. Sketch-based modeling and editing of 3D shapes

Participants: Marie-Paule Cani, Arnaud Emilien, Even Entem, Stefanie Hahmann, Rémi Ronfard.

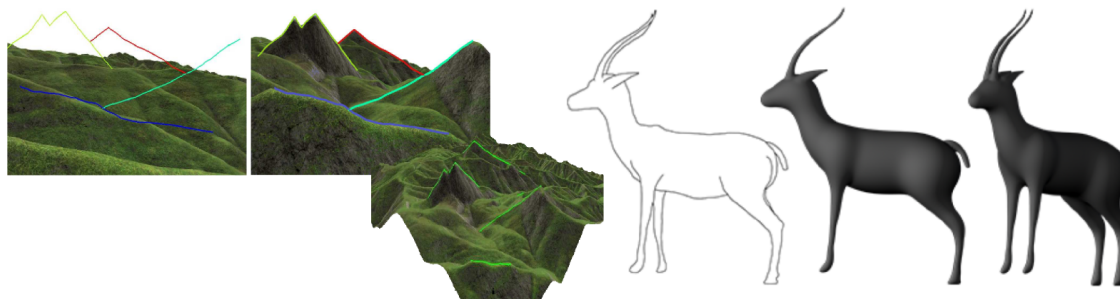


Figure 12. Illustration from [29](Left) showing our results on terrain editing, and from [6](Right) on 3D animal modeling from sketch.

While a lot of work has been done on sketch-based modeling of solid shapes, only a few methods do tackle surface models. Terrain surfaces are particular challenging: their fractal-like distribution of details makes them easy to identify, but these cannot be fully drawn by a user. In our work, users only need to draw the main silhouettes they would like to see from a first person viewpoint (enabling, for instance, an art director to set the background scene behind his actors). We generate a plausible, complex terrain that matches the sketch by deforming an existing terrain model. This is done by analyzing the complex silhouettes with cups and T-junctions in the input sketch and matching them with perceptually close features of the input terrain. The rest of the terrain is seamlessly deformed while keeping its visual complexity and style. This work was presented at Graphics Interface 2014 [29] and extended to enable the combination of silhouettes from multiple viewpoints in the Computer and Graphics journal [12].

In collaboration with UBC, we introduced the vector graphics complex (VGC), a simple data structure that supports non-manifold topological modeling for 2D vector graphics illustrations. The representation faithfully captures the intended semantics of a wide variety of illustrations, and is a proper superset of scalable vector graphics and planar map representations. VGC nearly separates the geometry of vector graphics objects from their topology, making it easy to deform objects in interesting and intuitive ways, a premise for enabling their animation. This work was published at SIGGRAPH 2014 [4]. We also developed a method for generating 3D animals from a single sketch. This method takes a complex sketch with cups and T-junctions as input (see Figure 12, and makes use of symmetry hypotheses to analyze it into regions corresponding to the main body and to front and back limbs. The different regions are then automatically reconstructed and blended together using our implicit modeling methodologies (SCALIS surfaces).

Lastly, we designed a sketch-based interface for authoring illustrative animations. The method makes use of hierarchical motion brushes, a new concept for specifying complex hierarchical motion with a few strokes [28].

6.5.2. Sketching and Sculpting Motion

Participants: Marie-Paule Cani, Arnaud Emilien, Kevin Jordao.

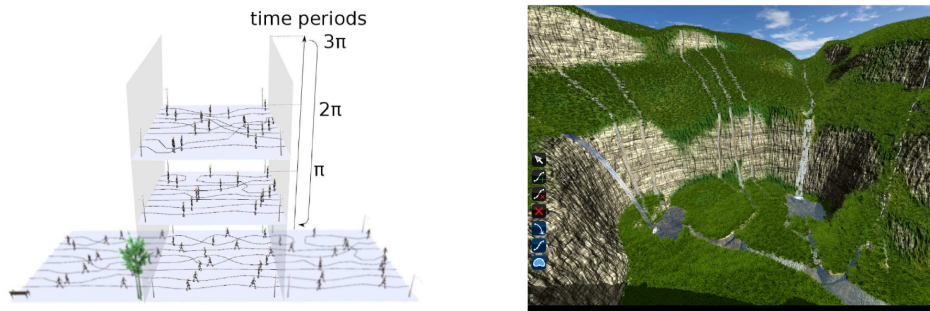


Figure 13. Illustration from [7](Left) on our crowd sculpting interface, and from [18](Right) on interactive design of complex waterfall scenes.

We extended sculpting methods, which had been restricted so far to homogeneous geometric models of a single dimension, to the handling of complex structured shapes and to the interactive sculpting of animated environments.

We developed the first method enabling to sculpt animated content in extending our previous elastic mutable model approach. Relying on the crowd patches representation for modeling animated crowds, we extended component mutations to space-time content, enabling a user to stretch, bend or assemble populated streets while ensuring that individual character trajectories remain continuous through space and time, as well as plausible. This work, developed within Kevin Jordao's thesis co-advised with Julien Pettré from the Mimetic project-team in Rennes, was published at Eurographics 2014 [7].

We developed an interactive system for designing complex waterfall scenes: vector elements created by the user (contacts, freefalls and pools) are used to control the procedural creation of complex waterfalls and rivers that match the user intend while ensuring coherent flows and good embedding within the terrain [18].

6.5.3. Interaction devices and gestural patterns

Participants: Marie-Paule Cani, Rémi Brouet.

Our work on gestural interaction patterns for 3D design has been developed in collaboration with the HCI team from LIG laboratory towards the exploration of 2D multi-touch tables for the placement and deformation of 3D models.

We are also exploring the use of multi-touch tables for the interactive design and editing of 3D scenes. This is the topic of Rémi Brouet's PhD thesis, co-advised with Renaud Blanch from the human-computer interaction group of LIG laboratory. The main challenge here is to find out how to use 2D interaction media for editing 3D content, hence how to intuitively control the third dimension (depth, non-planar rotations, 3D deformations, etc). Our work on this topic started with a preliminary user study enabling us to analyze all possible hand interaction gestures on table-tops, and to explore the ways users would intuitively try to manipulate 3D environments, either for changing the camera position or for moving objects around. We extracted a general interaction pattern from this study. Our implementation enables both seamless navigation and docking in 3D scenes, without the need for any menu or button to change mode. We are currently extending this work to object editing scenarios, where shapes can be bent or twisted in 3D using 2D interaction and automatic mode selection only.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts and Grants with Industry

7.1.1. *Airbus - Idealization of components for structural mechanics (06/2011 - 06/2014)*

Participants: Stefanie Hahmann, Jean-Claude Léon.

Cifre PhD in partnership with Airbus group to generate the shape of mechanical components through dimensional reduction operations as needed for mechanical simulations, e.g. transformations from volume bodies to shells or plates forming surface models, usually non-manifold ones. The topic addressed covers also the shape detail removal process that takes place during the successive phases where subsets of the initial shape are idealized. Mechanical criteria are taken into account that interact with the dimensional reductions and the detail removal processes. The goal is to define the transformation operators such that a large range of mechanical components can be processed as automatically and robustly as possible. Two major results have been obtained to generate construction graphs from CAD models and use a construction graph to generate a dimensionally reduced model suited for Finite Element Analyses.

7.1.2. *HAPTIHAND technology transfer project (Inria-HAPTION-Arts et Métiers ParisTech) (10/2012-08/2014)*

Participant: Jean-Claude Léon.

The objective is to transfer a device, named HandNavigator, that has been developed in collaboration with Arts et Métiers ParisTech/Institut Image, as add on to the 6D Virtuouse haptic device developed by HAPTION. The purpose of the HandNavigator is to monitor the movement of a virtual hand at a relatively detailed scale (movements of fingers and phalanxes), in order to create precise interactions with virtual objects like object grasping. This includes monitoring the whole Virtuouse 6D arm and the HandNavigator in a virtual environment, for typical applications of maintenance simulation and virtual assembly in industry. The project covers the creation of an API coupled to physical engine to generate and monitor a realistic and intuitive use of the entire device, the creation of physical prototypes incorporating multiple sensors for each user's finger. The physical prototypes have been developed using rapid prototyping technologies like the 3D printing device available from the Amigual4Home project (ANR-11-EQPX-0002).

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. *Scenoptique (12/2012 - 03/2014)*

Participant: Rémi Ronfard.

In October 2011, we started a collaboration with Theatre des Celestins in Lyon on the topic of interactive editing of rehearsals. This research program is funded by the Region Rhone Alpes as part of their CIBLE project, with a budget for a doctoral thesis (Vineet Gandhi) and three large sensor video cameras. Theatre des Celestins is interested in novel tools for capturing, editing and browsing video recordings of their rehearsals, with applications in reviewing and simulating staging decisions. We are interested in building such tools as a direct application and test of our computational model of film editing, and also for building the world's first publicly available video resource on the creative process of theatre rehearsal. Using state-of-the-art video analysis methods, this corpus is expected to be useful in our future work on procedural animation of virtual actors and narrative design. The corpus is also expected to be shared with the LEAR team as a test bed for video-based action recognition.

8.1.2. *Labex Persyval*

Participants: Rémi Ronfard, Olivier Palombi, Armelle Bauer.

We received a doctoral grant from LABEX PERSYVAL, as part of the research program on authoring augmented reality (AAR) for PhD student Adela Barbelescu. Her thesis is entitled *directing virtual actors by imitation and mutual interaction - technological and cognitive challenges*. Her advisors are Rémi Ronfard and Gérard Bailly (GIPSA-LAB).

Additionally, this project funds the PhD thesis of Armelle Bauer which has started in October, co-advised by François Faure, Olivier Palombi, and Jocelyne Troccaz from TIMC-GMCAO. The goal is to tackle the scientific challenges of visualizing one's self anatomy in motion using Augmented Reality techniques.

8.1.3. *TAPIOCA, Persyval Grant (11/2013 - 11/2015)*

Participants: Damien Rohmer, Jean-Claude Léon, Marie-Paule Cani.

Tapioca (Tangibilité Physiologique Instrumentée: Outil mixte redimensionnable pour la conception d'artefact) is a *projet exploratoire* of the Persyval Grant. This project aim to study the use of resizable interactive interface to ease the generation of virtual models. This project is in collaboration with LIG, Gipsa-lab and GSCOP.

8.2. National Initiatives

8.2.1. *ANR SOHUSIM (10/2010-09/2014)*

Participants: Ali Hamadi Dicko, François Faure.

Sohusim (Soft Human Simulation) is a ANR Project which started on October 1st 2010. It is done in collaboration between: EVASION (Inria), Fatronik France (TECNALIA), DEMAR (Inria), HPC PROJECT and the CHU de Montpellier.

This project deals with the problem of modeling and simulation of soft interactions between humans and objects. At the moment, there is no software capable of modeling the physical behavior of human soft tissues (muscles, fat, skin) in mechanical interaction with the environment. The existing software such as LifeMod or OpenSim, models muscles as links of variable length and applying a force to an articulated stiff skeleton. The management of soft tissues is not taken into account and does not constitute the main objective of this software.

A first axis of this project aims at the simple modeling and simulation of a passive human manipulated by a mecatronics device with for objective the study and the systems design of patient's manipulation with very low mobility (clinic bed). The second axis concentrates on the detailed modeling and the simulation of the interaction of an active lower limb with objects like orthosis, exoskeleton, clothes or shoes. The objective being there also to obtain a tool for design of devices in permanent contact with the human who allows determining the adequate ergonomics in terms of forms, location, materials, according to the aimed use.

8.2.2. *ANR CORPUS SPECTABLE EN LIGNES (01/2013-01/2015)*

Participant: Rémi Ronfard.

Spectacle En Ligne(s) amplifies our collaboration with the Theatre des Celetins in Lyon, which was started with the Scenoptique project in 2011. Scenoptique investigates novel techniques for recording ultra-high definition video, reframing them and editing them into interactive movies. Spectacle En Ligne(s), is targeted on the creation and diffusion of an original data set of integral video recordings of theatre and opera rehearsals. The data set is naturally suited to researchers interested in the creation process and the genetic analysis of dramatic art and mise en scene. To support research in this area, we are extending the audio and visual analysis tools developed in the Scenoptique project.

8.2.3. *FUI Dynam'it (01/2012 - 02/2014)*

Participant: Francois Faure.

2-year contract with two industrial partners: TeamTo (production of animated series for television) and Artefacts Studio (video games). The goal is to adapt some technologies created in SOFA, and especially the frame-based deformable objects [43], [42] to practical animation tools. This contract provides us with the funding of two engineers and one graphical artist during two years.

8.2.4. *FUI Collodi (October 2013 - October 2016)*

Participants: Francois Faure, Romain Testylier.

This 3-year contract with two industrial partners: TeamTo and Mercenaries Engineering (software for production rendering), is a follow-up and a generalization of Dynamit. The goal is to propose an integrated software for the animation and final rendering of high-quality movies, as an alternative to the ever-ageing Maya. It will include dynamics similarly to Dynamit, as well as innovative sketch-based kinematic animation techniques invented a Imagine by Martin Guay and Rémi Ronfard. This contract, started in October, funds 2 engineers for 3 years.

8.2.5. *ANR CHROME (01/2012 - 08/2015)*

Participant: Rémi Ronfard.

Chrome is a national project funded by the French Research Agency (ANR). The project is coordinated by Julien Pettré, member of MimeTIC. Partners are: Inria-Grenoble IMAGINE team (Remi Ronfard), Golaem SAS (Stephane Donikian), and Archivideo (Francois Gruson). The project has been launched in september 2012. The Chrome project develops new and original techniques to massively populate huge environments. The key idea is to base our approach on the crowd patch paradigm that enables populating environments from sets of pre-computed portions of crowd animation. These portions undergo specific conditions to be assembled into large scenes. The question of visual exploration of these complex scenes is also raised in the project. We develop original camera control techniques to explore the most relevant part of the animations without suffering occlusions due to the constantly moving content. A long-term goal of the project is to enable populating a large digital mockup of the whole France (Territoire 3D, provided by Archivideo). Dedicated efficient human animation techniques are required (Golaem). A strong originality of the project is to address the problem of crowded scene visualisation through the scope of virtual camera control, as task which is coordinated by Imagine team-member Rémi Ronfard.

Three phd students are funded by the project. Kevin Jordao is working on interactive design and animation of digital populations and crowds for very large environments. His advisors are Julien Pettré and Marie-Paule Cani. Quentin Galvanne is working on automatic creation of virtual animation in crowded environments. His advisors are Rémi Ronfard and March Christie (Mimetic team, Inria Bretagne). Julien Pettre. Chen-Kin Lim is working on crowd simulation and rendering of the behaviours of various populations using crowd patches. Her advisors are Rémi Ronfard and March Christie (Mimetic team, Inria Bretagne). Julien Pettre.

8.2.6. *Action3DS (Caisse des dépôts) (10/2011 - 09/2014)*

Participant: Rémi Ronfard.

Action3DS is a national project funded by Caisse des Dépôts, as part of the *projet Investissements d'avenir ACTION3DS* research program entitled *Technologies de numérisation et de valorisation des contenus culturels, scientifiques et éducatifs*.

The project is coordinated by Thales Angénioux (Patrick Defay). Partners are Inria (Rémi Ronfard), Lutin Userlab (Charles Tijus), LIP6 (Bernadette Bouchon-Meunier), GREYC (David Tschumperlé), École nationale supérieure Louis Lumière (Pascal Martin), Binocle (Yves Pupulin), E2V Semiconductors and Device-Alab.

The goal of the project is the development of a compact professional stereoscopic camera for 3D broadcast and associated software. Rémi Ronfard is leading a work-package on real-time stereoscopic previsualization, gaze-based camera control and stereoscopic image quality.

The project is funding our new postdoc researcher Christophe Lino who is working on learning-based camera control for stereoscopic 3D cinematography with Rémi Ronfard.

8.2.7. *AEN MorphoGenetics (10/2012 - 09/2015)*

Participant: François Faure.

3-year collaboration with Inria teams Virtual Plants and Demar, as well as INRA (Agricultural research) and the Physics department of ENS Lyon. The goal is to better understand the coupling of genes and mechanical constraints in the morphogenesis (creation of shape) of plants. Our contribution is to create mechanical models of vegetal cells based on microscopy images. This project funds the Ph.D. thesis of Richard Malgat, who started in October, co-advised by François Faure (IMAGINE) and Arezki Boudaoud (ENS Lyon).

8.2.8. *PEPS SEMYO (10/2012 - 09/2014)*

Participant: François Faure.

2-year collaboration with Inria team DEMAR (Montpellier) and Institut de Myologie (Paris) to simulate 3D models of pathological muscles, for which no standard model exist. The main idea is to use our mesh-less frame-based model to easily create mechanical models based on segmented MRI images.

8.3. European & International Initiatives

8.3.1. *ERC Grant Expressive (04/2012-03/2017)*

Participants: Marie-Paule Cani, Stefanie Hahmann, Jean-Claude Léon.

To make expressive and creative design possible in virtual environments, the goal is to totally move away from conventional 3D techniques, where sophisticated interfaces are used to edit the degrees of freedom of pre-existing geometric or physical models: this paradigm has failed, since even trained digital artists still create on traditional media and only use the computer to reproduce already designed content. To allow creative design in virtual environments, from early draft to progressive refinement and finalization of an idea, both interaction tools and models for shape and motion need to be revisited from a user-centred perspective. The challenge is to develop reactive 3D shapes – a new paradigm for high-level, animated 3D content – that will take form, refine, move and deform based on user intent, expressed through intuitive interaction gestures inserted in a user-knowledge context. Anchored in Computer Graphics, this work reaches the frontier of other domains, from Geometry, Conceptual Design and Simulation to Human Computer Interaction.

8.3.2. *Piper (2013-2017)*

The main objective of this European FP7 project is to develop new tools to position and personalize advanced human body models for injury prediction in car crashes. Our partners are automobile constructors and biomechanics research labs. Our main task is to provide tools for the interactive positioning of the models in the cockpits prior to the crash simulation, using our real-time simulation software SOFA. This 42-month contract funds one engineer in Imagine, and we plan to hire post-doc students next year.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Bob Sumner: Character depiction, posing and synthesis, Disney Research (Zurich) (13/11/2014).
- Tamy Boubekeur: Spatial, Statistical and Morphological Analysis for 3D Shape Modeling, Telecom ParisTech (23/10/2014)
- Jacob Wenzel: Capturing and simulating the interaction of light with the world around us, ETH Zurich (09/10/2014)
- Mariët Theune: Nicolas Szilas, Ulrike Spierling, Paolo Petta, Remi Ronfard. Storytelling seminar (21/07/2014)
- Mark Finlayson: Learning Narrative Structure from Annotated Stories, MIT (03/07/2014)
- Matthias Teschner: Particle-based Fluid Simulation, University of Freiburg (17/06/2014)
- Melina Skouras. Design and Fabrication of Deformable Objects, ETH Zurich (05/06/2014)
- Boris Thibert. Flat torus and smooth fractals, LJK Grenoble (15/05/2014)
- Olga Sorkine. Reality-inspired constraints for shape modeling and editing, ETH Zurich (28/03/2014)
- Jernej Barbic: Model reduction for elasticity problems in computer graphics and animation, University of Southern California (02/27/2014)
- Chris Wojtan: Compensating for Defects in Geometric Models and Liquid Surfaces, IST Austria (02/20/2014)

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. general chair, scientific chair

- Rémi Ronfard was chair for the 3rd AAAI workshop on Cinematography and Film Editing (WICED'2014), which took place on July 30, 2014 in Quebec City, Canada. He was also co-chair for the 4th Eurographics workshop on Cinematography and Film Editing (WICED'2015), which will take place on May 4, 2015, in Zurich, Switzerland.
- Stefanie Hahmann was co-organizer of the 9th international colloque *Dagstuhl Seminar on Geometric Modeling* et the Leibniz-Zentrum für Informatik en Allemgane. 45 invited researchers participated to scientific talks, discussions and perspective working groups.

9.1.1.2. member of the organizing committee

- Marie-Paule Cani was a steering committee member of SMI (Shape Modelling International) and Expressive (SBIM, NPAR, CAe) Chair of the Steering committee of Eurographics.
- Rémi Ronfard was member of the following events
 - International Conference on Interactive Digital Storytelling (ICDS 2014).
 - Computational Modeling of Narrative (CMN 2014).
 - Interactive Narrative Technologies (INT 2014).
 - SIGGRAPH workshop on Motion in Games (MIG 2014).
 - International Conference on 3D imaging (IC3D 2014).
 - International Conference on Intelligent Human Computer Interaction (IHCI 2014).

9.1.2. Scientific events selection

9.1.2.1. member of the conference program committee

- Marie-Paule Cani was member of the conference program committee for Graphics Interface 2014 and Expressive 2014 (joint ACM-EG symposium on SBIM, NPAR, CAe).
- Stefanie Hahmann was member of the international program committee for Eurographics 2014, SMI' 14 Shape Modeling International, Computer Graphics International (CGI' 14), and SPM 2014 Symposium on Solid and Physical Modeling.
- Damien Rohmer was member of the Technical Briefs & Poster for ACM SIGGRAPH Asia 2014.

9.1.2.2. reviewer

- Marie-Paule Cani was reviewer for SIGGRAPH 2014.
- Stefanie Hahmann was reviewer for Eurographics 2014, SMI' 14, CGI' 14 and SPM' 14.
- Jean-Claude Léon was reviewer for CAD 2014 Intl conference.
- Damien Rohmer was reviewer for SIGGRAPH Asia 2014 and Eurographics 2014.

9.1.3. Journal

9.1.3.1. member of the editorial board

- Marie-Paule Cani was member of the editorial board of ACM Transactions on Graphics (TOG).
- Stefanie Hahmann was reviewer for Computer Aided Design (Elsevier) and Graphical Models (Elsevier).
- Jean-Claude Léon was member of the editorial board of Computer Aided Design.

9.1.3.2. reviewer

- Jean-Claude Léon was reviewer for Computer Aided Design.
- Olivier Palombi was reviewer for Surgical and Radiologic Anatomy.
- Rémi Ronfard was reviewer for The Visual Computer, and Computer Vision and Image Understanding.
- Damien Rohmer was reviewer for the popularization journal Quadrature.

9.1.4. Others

Marie-Paule Cani was

- Vice chair of the European scientific organization Eurographics
- Elected member of EG-France executive committee (french chapter of Eurographics)
- Member of the ACM publication board until June 2014.
- Member of the scientific council of ESIEE Paris.

Stefanie Hahmann was

- Member of the SMA Executive Committee (Shape Modeling Association).
- President of GTMG (Groupe de Travail en Modélisation Géométrique) part of GDR IM and GDR IGRV.
- Member of the Conseil du Laboratoire at LJK.
- Responsible of Maths-Info department of the Grenoble doctoral school MSTII.

Rémi Ronfard

- gave invited talks on "Directing virtual worlds" at Utrecht University; at Laboratoire d'Informatique Fondamentale in Marseille; at LIRIS in Lyon; at IRCAM in Paris.
- is a co-organizer of the GDR ISIS action on "Face, gesture, action and behavior", which held its national meeting on December 11, at Telecom Paris Tech.
- is a member of the new GDR Esars : *Esthétique, Art et Science*.

9.2. Teaching - Supervision - Juries

9.2.1. Responsibilities of academic programs

- Marie-Paule Cani is responsible for two courses at Ensimag/Grenoble-INP: 3D Graphics (a course that attracts about 80 master 1 students per year) and IRL (Introduction à la recherche en laboratoire), a course enabling engineering students to work on a personal project in a research lab during one semester, to get an idea of what academic research is.
- Stefanie Hahmann is co-responsible of the MMIS (Images and Applied Maths) (<http://ensimag.grenoble-inp.fr/cursus-ingenieur/modelisation-mathematique-images-simulation-124674.kjsp>) department at University ENSIMAG/Grenoble INP. Stefanie Hahmann is responsible of 3 courses at Ensimag/Grenoble INP: Numerical Methods (240 students, 3rd year Bachelor level), Geometric Modeling (60 students, Master 1st year) and Surface Modeling (30 students, Master 2nd year).
- Olivier Palombi is responsible of the French **Campus numérique** of anatomy. Olivier Palombi is responsible and national leader of the project SIDES (<http://side-sante.org/>). All the French medical schools (43) have planed to use the same e-learning framework (SIDES) to manage evaluations (examen) and to create a large shared database of questions.
- François Faure was responsible of the GVR-(Graphics, Vision and Robotic) programm in the MOSIG Master.
- Damien Rohmer is coordinator of the Math-Signal-Image program in the school CPE Lyon.
- Rémi Ronfard taught courses in Advanced 3D animation, M2R MOSIG, University of Grenoble (12 hours); and Game Engine Programming, M2R IMAGINA, University of Montpellier (20 hours).

Note that MOSIG is joint master program between University Joseph Fourier (UJF) and Institut Polytechnique de Grenoble (INPG) taught in English since it hosts a number of internal students. It belongs to the doctoral school MSTII.

9.2.2. Educational activities

Most of the members of our team are Professor or Assistant Professor in University where the common teaching load is about 200h per year. Rémi Ronfard who is only researcher usually perform some teaching in delegation.

9.3. Popularization

Damien Rohmer published an article on volume preserving deformation in Quadrature Journal [41]. This journal is accessible for University students and teachers.

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

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