

*Project-Team EVASION**Virtual environments for animation and
image synthesis of natural objects**Rhône-Alpes*

THEME COG

The logo features the word "Activity" in a white serif font, with a large, light grey, stylized letter "A" to its left. A horizontal line passes through the middle of the "A" and the word "Activity". Below this, the word "Report" is written in a white serif font, with a large, light grey, stylized letter "R" to its left.

2004

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1. Team

The EVASION team, GRAVIR-IMAG laboratory (UMR 5527), is a joint project between CNRS, INRIA, Institut National Polytechnique de Grenoble (INPG) and Université ½ Joseph Fourier (UJF).

Head of the project

Marie-Paule Cani [Professor, INPG]

Staff member

Anne Pierson [Administrative Assistant, INPG]

Technical staff

Philippe Decaudin [Engineer, Project RIAM VERTIGO]

Christine Depraz [Graphics Designer, Project RIAM Virtual Actors]

Laure Heïgés [Engineer, Project RNTL PARI]

Research scientist

Fabrice Neyret [Research scientist, CNRS CR1]

Lionel Reveret [Research Scientist, INRIA CR2]

Faculty member

Georges-Pierre Bonneau [Professor, UJF]

François Faure [Assistant Professor, UJF]

Frank Héttroy [Assistant Professor, INPG]

Post-doctoral fellow

Alexandre Meyer [Teaching Assistant, UJF]

Thanh Giang [Project RIAM Virtual Actors, INPG]

PhD. student

Florence Bertails [MENRT, INPG, EVASION]

Antoine Bouthors [MENRT, UJF, EVASION]

Jean Combaz [MENRT, UJF, EVASION]

Mathieu Coquerelle [MENRT, INPG, EVASION]

Guillaume Dewaele [AMN, INPG, MOVI/EVASION]

Laurent Favreau [MENRT, INPG, EVASION]

Olivier Galizzi [MENRT, INPG, EVASION/L3S]

Caroline Larboulette [MENRT, Rennes I, SIAMES/EVASION]

Sylvain Lefebvre [MENRT, UJF, EVASION]

Matthieu Nesme [MENRT, UJF, EVASION]

Frank Perbet [MENRT, INPG, EVASION]

Alexandre Perrin [Cifre at Virtual Actors, INPG, Virtual Actors/EVASION]

Laks Raghupathi [Project RIAM Virtual Actors, INPG, EVASION]

Basile Sauvage [MENRT, INPG, LMC/EVASION]

Fabien Vivodtzev [Grant from CEA, UJF, CEA-CESTA/EVASION]

Alex Yvart [BDI-CNRS, INPG, LMC/EVASION]

External collaborators

Alexis Angelidis [PhD. student, University of Otago (New Zealand)]

Olivier Palombi [PhD. student, Anatomy Laboratory, Medicine Faculty of Grenoble]

Visiting scientist

John Hughes [Professor, Brown University (USA)]

2. Overall Objectives

The EVASION project addresses the synthesis of images of natural scenes and phenomena. This aim leads

us to work jointly on the specification, representation, animation, visualisation and rendering of these scenes. In addition to the high impact of this research on audiovisual applications (3D feature films, special effects, video games), the rising demand for efficient visual simulations in areas such as environmental and medical applications is also addressed. We thus study objects from the animal, mineral and vegetable realm, all being possibly integrated into a complex natural scene. We constantly seek a balance between efficiency and visual realism. This balance depends on the application (e.g., the design of immersive simulators requires real-time, while the synthesis of high quality images may be the primary goal in other applications).

3. Scientific Foundations

The synthesis of natural scenes has only been very recently studied compared to that of manufacturing environments, due to the difficulty in handling the high complexity of natural objects and phenomena. This complexity can express itself either in the number of elements (e.g. a prairie, hair), in the complexity of the shapes (e.g., many vegetable forms or animal organisms), from motions (e.g. a cloud of smoke, a stream), or from the local appearance of the objects (a lava flow).

To tackle this challenge:

- we exploit *a priori* knowledge from other sciences as much as possible, in addition to inputs from the real world such as images and videos;
- we take a transversal approach with respect to the classical decomposition of Computer Graphics into Modelling, Rendering and Animation: we instead study the modelling, animation and visualisation of a phenomenon in a combined manner;
- we reduce computation time by developing alternative representations to traditional geometric models and finite element simulations: hierarchies of simple coupled models instead of a single complex model; multi-resolution models and algorithms; adaptive levels of detail;
- we take care to keep an intuitive user control;
- we validate our results through the comparison of real phenomena, based on perceptual criteria.

Our research strategies are twofold:

1. **Development of fundamental tools**, i.e. of new models and algorithms satisfying the conditions above. Indeed, we believe that there are enough similarities between natural objects to factorise our efforts by the design of these generic tools. For instance, whatever their nature, natural objects are subject to physical laws that constrain their motion and deformation, and sometimes their shape (which results from the combined actions of growth and aging processes). This leads us to conduct research in adapted geometric representations, physically-based animation, collision detection, and phenomenological algorithms to simulate growth and aging phenomena. Secondly, the high number of details, sometimes similar at different resolutions, that can be found in natural objects, leads us to the design of specific adaptive or multi-resolution models and algorithms. Lastly, being able to efficiently display very complex models and data-sets is required in most of our applications, which leads us to contribute to the visualisation domain.
2. **Validation of these models by their application to specific natural scenes**. We cover scenes from the animal (animals in motion, parts of the human body, from internal organs dedicated to medical applications to skin, faces and hair needed for character animation), vegetable (complex vegetable shapes, specific material such as tree barks, animated prairies, meadows and forests) and mineral (lava-flows, mud-flows, avalanches, streams, smoke, cloud) realms.

4. Application Domains

4.1. Introduction

The fundamental tools we develop and their applications to specific natural scenes are opportunities to enhance our work through collaborations with both industrial partners and scientists from other disciplines (the current collaborations are listed in 8.). This section briefly reviews our main application domains.

4.2. Audiovisual applications: Special effects and video games

The main industrial applications of the new representations, animation and rendering techniques we develop, in addition to many of the specific models we propose for natural objects, are in the audiovisual domain: a large part of our work is used in joint projects with the special effects industry and/or with video games companies.

4.3. Medical applications: Virtual organs and surgery simulators

Some of the geometric representations we develop, and their efficient physically-based animations, are particularly useful in medical applications involving the modelling and simulation of virtual organs and their use in either surgery planning or interactive pedagogical surgery simulators. All of our applications in this area are developed jointly with medical partners, which is essential both for the specification of the needs and for the validation of results.

4.4. Environmental applications and simulation of natural risks

Some of our work in the design and rendering of large natural scenes (mud flows, rock flows, glaciers, avalanches, streams, forests, all simulated on a controllable terrain data) lead us to very interesting collaborations with scientists of other disciplines. These disciplines range from biology and environment to geology and mechanics. In particular, we are involved in inter-disciplinary collaborations in the domains of impact studies and simulation of natural risks, where visual communication using realistic rendering is essential for enhancing simulation results.

4.5. Applications to industrial design and interactive modelling software

Some of the new geometrical representations and deformation techniques we develop lead us to design novel interactive modelling systems. This includes for instance applications of implicit surfaces, multi-resolution subdivision surfaces, space deformations and physically-based clay models. Some of this work is exploited in contacts and collaborations with the industrial design industry.

4.6. Applications to scientific data visualisation

Lastly, the new tools we develop in the visualisation domain (multi-resolution representations, efficient display for huge data-sets) are exploited in several industrial collaborations; for instance within the energy and drug industries. These applications are dedicated either to the visualisation of simulation results or to the visualisation of huge geometric datasets (an entire power plant, for instance).

5. Software

5.1. Introduction

Although software development is not among our main objectives, the various projects we are conducting lead us to conduct regular activities in the area, either with specific projects or through the development of general libraries. This section only describes the few softwares we are developing for the public domain.

5.2. AnimAL

Participants: Florence Bertails, François Faure, Olivier Galizzi, Laure Heïgés, Caroline Larboulette, Laks Raghupathi.

AnimAL is a C++ library mostly dedicated to animation of 3D models. The kernel of AnimAL is intended to be highly flexible thanks to generic programming (templates). It includes classes representing basic variables (arrays, rotations, solid transforms, linear algebra, etc.) as well as standard algorithms (numerical integration, optimisation, interpolation, etc.). This kernel uses only standard libraries of C++. Thus it is totally independent of the other modules and is directly portable on another architecture or system.

Actually, except the basic tools and the standard algorithms, the existing code in AnimAL is mainly due to the result of our research code (physical mass-spring system, collision detection). We recently proposed its integration into a new modular architecture, supporting input-output of 3D files, internal 3D scene graphs, and graphic user interface which allows the control of the animation and the viewing of the animated 3D models. This architecture is partly based on free softwares developed by the ARTIS team (X3DToolkit and QGLViewer).

AnimAL, in its preliminary form, was already used within four collaborations:

1. with the LIGIM research laboratory at Lyon. The goal was to model and animate fractured materials.
2. with the LIFL research laboratory at Lille. Some parts of AnimAL were used in a surgical simulator.
3. with the University of Lecce (Italy).
4. with the University of Tuebingen (Germany) for cloth simulation.

The actual version of AnimAL has been used in the RNTL project PARI (see section 7.2), and in the RIAM project Virtual Actors (see section 7.3) with the video games company Galilea at Grenoble.

In the future, AnimAL will integrate all of the new animation technologies we develop at EVASION, and will become an open source C++ library (see <http://www-evasion.imag.fr/Ressources>).

5.3. gluX

Participant: Sylvain Lefebvre.

The OpenGL graphics programming API is widely used by researchers to work with recent graphics hardware. To access hardware-specific functions, it relies on an extension loading mechanism. Due to the large variety of video card models it is very important to be able to check if extensions are available at runtime. Moreover the same program often needs to include different versions of the same rendering code in order to adapt to the set of available extensions. Unfortunately, the loading mechanism provided by OpenGL is different under Linux and Windows platforms, and requires a large amount of very repetitive loading code for each extension (more than 200 extensions are available). gluX is a cross-platform easy-to-use OpenGL extension loader (see <http://www-evasion.imag.fr/Ressources>). It offers a very simple mechanism for loading and using OpenGL extensions. It allows to detect at runtime if the required extensions are present or not and to select the appropriate rendering code. It is a very convenient tool as it allows to exchange programs without having to handle the painful task of writing the extension loading code for each platform and video card model.

5.4. MobiNet

Participants: Sylvain Lefebvre, Fabrice Neyret.

The MobiNet software allows for the creation of simple applications such as video games or pedagogic illustrations relying on an intuitive graphical interface and language which allows for the ability to program a set of mobile objects (possibly through a network). It is available in public domain for Linux and Windows at <http://www-evasion.imag.fr/mobinet/>. It originated from 4 members of EVASION and ARTIS (including a "monitorat" project). The main aim is pedagogical: MobiNet allows young students at high school level with no programming skills to experiment, with the notions they learn in math and physics by creating simple video

games. This platform is massively used during the INPG "engineer weeks": 150 senior high school pupils per year, doing a 3 hour practice. This work is partly funded by INPG. Various contacts are currently developed in the educational world. Our results were published in the educational program of Eurographics'04 [21].

6. New Results

6.1. New representations and deformation techniques for shape modelling

Participants: Alexis Angelidis, Georges-Pierre Bonneau, Antoine Bouthors, Marie-Paule Cani, Franck Hétroy, Fabrice Neyret, Basile Sauvage, Alex Yvart.

6.1.1. Detection of geometrical and topological characteristics in shapes

Participant: Franck Hétroy.

This work has just started this Fall with the arrival of a new assistant professor in EVASION.

The purpose of this research is to modelize and compute several geometrical or topological characteristics on surfaces or in volumes. The first part of this work, currently carried out, is the detection of "constriction areas" on a closed surface. We define constrictions as simple closed curves with locally minimal length, and use simple curve and path computation algorithms to construct them.

Applications of this work are widespread, from classification of shapes to object decomposition into simple parts, and to detection of singularities.

6.1.2. Multiresolution surfaces

Participants: Georges-Pierre Bonneau, Alex Yvart.

This research is done in collaboration with Stefanie Hahmann from the LMC/IMAG. The aim is to define a representation of surfaces that combines the advantages of subdivision surfaces and NURBS surfaces, for use in CAD/CAM systems, or Animation software. Subdivision surfaces can represent surfaces of arbitrary topology, with the ability to efficiently encode local detail information. But they suffer from the lack of an explicit parametric formulation, which is required by many techniques in CAD/CAM systems, including surface interrogation, trimming, offsetting... On the other hand, NURBS surfaces are not efficient for representing surfaces of arbitrary topology. A new surface model has been developed, that is defined by low degree polynomial patches that connect smoothly with G1-continuity. Last year it has been shown how this model can be hierarchically refined in order to compactly add local detail on the surface. A paper on this topic has been submitted for publication at ACM Transactions On Graphics. Figure 1 illustrates a dog's head designed with a geometric modelling software based on our new surface model. Thereafter automatic reconstruction techniques have been developed, that takes as input a dense triangular mesh, and outputs a compact surface representation using our new model. The reconstruction method has been submitted for publication at SMI'05. Figure 2 illustrates the reconstruction of the Max Planck model. Alex Yvart has defended his PhD on this topic in December 2004.

6.1.3. Multiresolution geometric modelling with constraints

Participants: Georges-Pierre Bonneau, Basile Sauvage.

This work is done in collaboration with Stefanie Hahmann from LMC/IMAG. A collaboration has also started on this topic with Prof. Gershon Elber from Technion, in the framework of the Aim@Shape Network of Excellence (see Section 8.3.1). The purpose of this research is to allow complex non-linear geometric constraints in a multiresolution geometric modelling environment. Two kinds of constraints have been investigated so far: constraints of constant area and constant length, both for the modelling of curves. For the area constraint, a wavelet decomposition of the curve has been used, and the bilinear form corresponding to the area enclosed by the curve has been expressed in this wavelet basis. This enables us to enforce a constant area constraint in real time, even for complex curves with an order of 1000 control points. This work has been submitted for publication in the journal Computer Aided Geometric Design. Concerning the constraint of

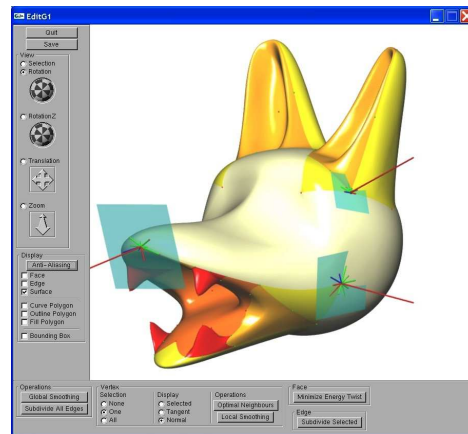


Figure 1. Design of a canine head using geometric modelling software based on our new surface model which adds local surface detail through hierarchical refinement.

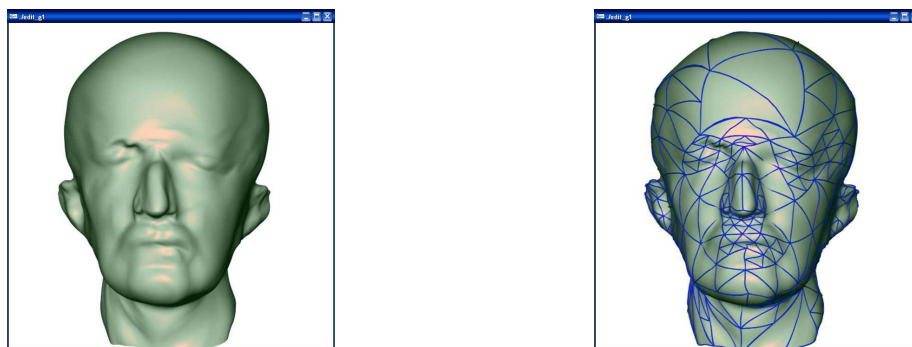


Figure 2. Results of an automatic reconstruction of a dense Max Planck bust model to a more compact surface representation defined by our new surface model

constant length, a multiresolution editing tool for planar curves which allows maintaining a constant length has been developed. One possible application is the modelling of folds and wrinkles. This work has been published in [8].

The generalization of these results to constraint of constant volume and constant area in the modelling of surfaces is currently under investigation.

6.1.4. Space deformations

Participants: Alexis Angelidis, Marie-Paule Cani.

We developed a new method based on space deformations for interactively sculpting a shape while keeping its topological genus unchanged: the user interactively sweeps tools that deform space along their path. The objects that overlap with the deformed part of the space are re-meshed in real-time for always being accurately displayed. Our method insures that the resulting deformations are fold over-free, which prevents self-intersections between parts of the deformed shapes. Our paper [11] got the best paper award at the Shape Modelling International'2004 conference. The extension of this work to constant volume space deformations makes the interaction even more intuitive, since objects now deform as if they were made of real material (see Figure 3). This work was presented as a technical sketch at SIGGRAPH [29], and the full paper [10] got the best paper award at the Pacific Graphics'2004 conference.

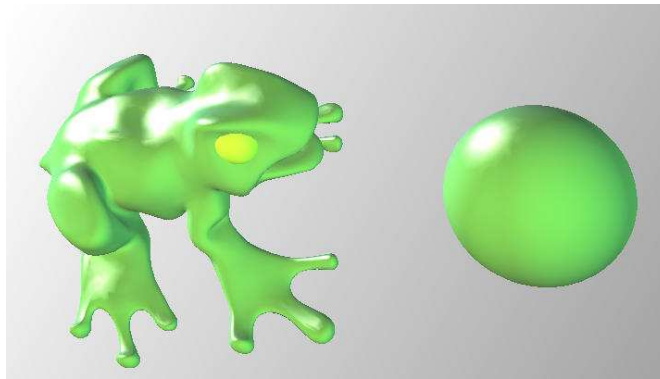


Figure 3. Constant volume spacial deformation

6.1.5. Cumulus clouds shape model

Participants: Antoine Bouthors, Fabrice Neyret.

During his Master thesis Antoine Bouthors has developed a model of cumulus cloud shape which is surface based. The mesh of the surface is produced from hierarchical implicit blobs on top of each other. Blobs are associated to particles repulsing each other. Their shape is defined by a potential keeping their well-separated and spherical aspect while ensuring continuity through blobs. A dedicated shader allows us to provide a fuzzy appearance to the surface (see figure 4). This work has been published as a short presentation [13] at Eurographics'04. Antoine Bouthors is now continuing his work as a PhD student.

6.2. Textural methods

Participants: Philippe Decaudin, Sylvain Lefebvre, Fabrice Neyret.

6.2.1. Textures sprites

Participants: Sylvain Lefebvre, Fabrice Neyret.

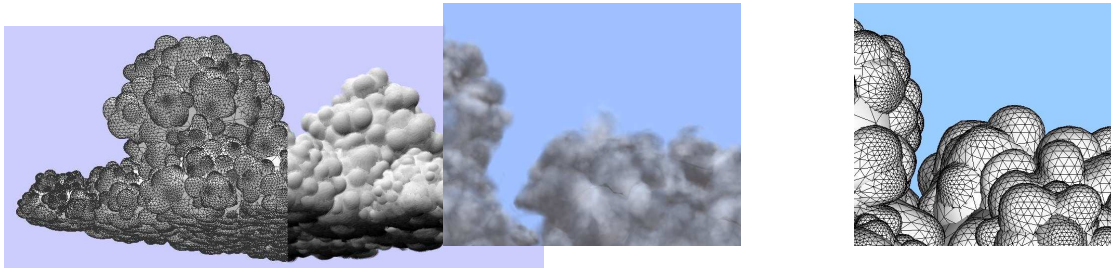


Figure 4. The resulting mesh, and the pseudo-volume rendering.

We developed a parameterization-free texture representation capable of defining high resolution details on surfaces without distortion (see figure 5). It draws on octree-textures (surface colour data is stored in a volumetric octree) and sprites (small repeated images relying on a set of reference patterns): our representation stores the location and orientation of the pattern instances in the octree.

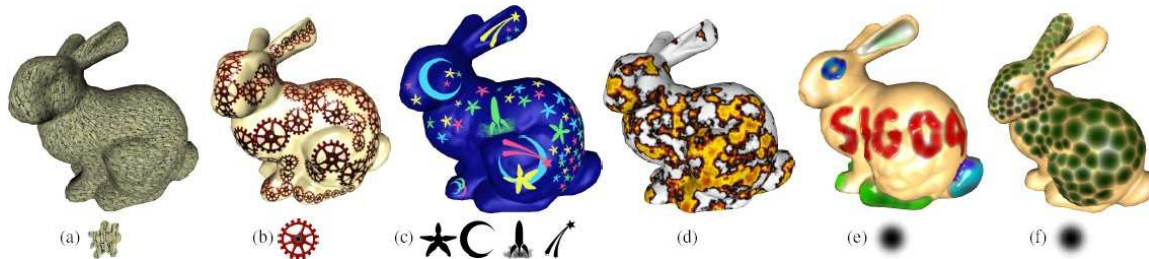


Figure 5. Six ways to texture a rabbit.

Our goal is to make the model GPU-compliant, which means that the data structures lie on the graphics board: It must be dynamically updatable from the CPU by an application (e.g. a painting tool). At run time, our algorithm implemented as a dedicated *fragment shader* must be able to recover the texture colour for any given pixel.

This work [27] is under submission. A detailed partial version has been accepted for publication as a chapter in the book GPU-Gems II [33].

6.2.2. Extended Clipmaps

Participants: Sylvain Lefebvre, Fabrice Neyret.

We developed a representation for very large or very detailed textures which cannot enter in memory (see figure 6). Like SGI clipmaps, it relies on a hierarchical tiled MIPmap pyramid. The principle is that for a given view, either a large low-resolution or a narrow high-resolution part of the texture is visible, so that only a small subset of tiles are needed in memory. Our representation includes a dedicated cache system and an algorithm capable of determining which tiles are required at which resolution (including view-frustum culling).

Our goal is to make the model GPU-compliant (i.e. we work directly in *texture space*). This allows us to emulate a full-resolution texture transparently for an application. Moreover, we propose a general scheme including a *texture producer* which can process operations more complex than just fetching a texture tile from disk (e.g. it can decompress or procedurally generate it, possibly on GPU).

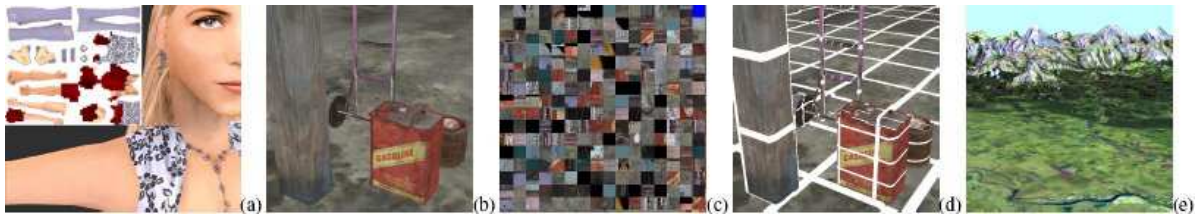


Figure 6. *a*: visible parts of the texture are figured in red in the texture. *b,c,d*: a view in a complex textured scene, the corresponding texture cache, and the corresponding texture-space tiling. *d*: flyover and zoom on a textured terrain.

This work is under submission. Note that Sylvain Lefebvre will defend his PhD in early 2005.

6.2.3. Texture packing

Participants: Philippe Decaudin, Fabrice Neyret.

Sets of square texture tiles of the same size are often used in Computer Graphics, especially for real-time 3D applications (VR, video games, etc.). It is often important to gather the tiles together in one large texture to avoid performance penalty due to graphic context switching while rendering. It is also easier to manage one large texture instead of a set of small ones. But constraints imposed on texture size by graphics hardware make it difficult to pack an arbitrary number of tiles without too much space loss.

In this work, we have proposed a new packing scheme (see figure 7) which allows the packing of many number of tiles with no loss. These numbers (e.g. 10, 17...) cannot be reached with common packing schemes.

This work has been published as a short presentation [14] at Eurographics'04.

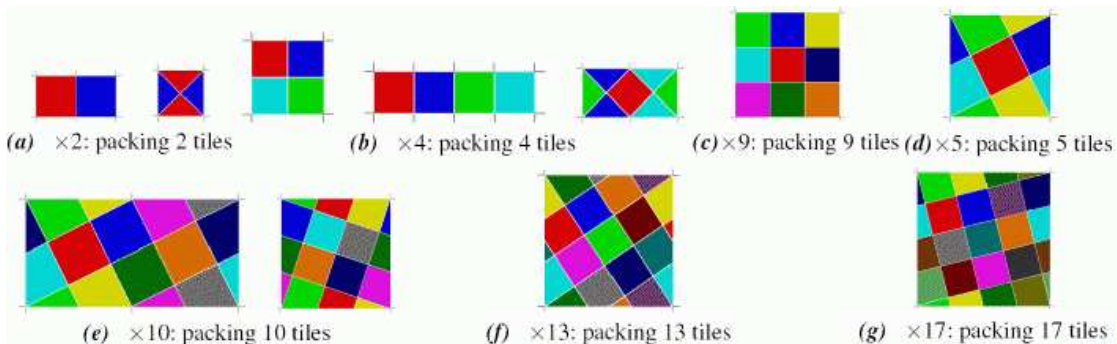


Figure 7. Various number of tiles compressed with no loss of tile space using our scheme.

6.3. Visualization of Scientific Data

Participants: Georges-Pierre Bonneau, Stéphane Ploix, Fabien Vivodtzev.

6.3.1. Hierarchical segmentation of shapes based on curvature

Participants: Georges-Pierre Bonneau, Fabien Vivodtzev.

This project is part of a collaboration with IDAV (<http://www.idav.ucdavis.edu/>). A high-level approach to describe the characteristics of a surface is to segment it into regions of uniform curvature behavior and

construct an abstract representation given by a (topology) graph. We propose a surface segmentation method based on discrete mean and Gaussian curvature estimates. The surfaces are obtained from three-dimensional imaging data sets by isosurface extraction after data presmoothing and postprocessing the isosurfaces by a surface-growing algorithm. We generate a hierarchical multiresolution representation of the iso-surface. Segmentation and graph generation algorithms can be performed at various levels of detail. At a coarse level of detail, the algorithm detects the main features of the surface. This low-resolution description is used to determine constraints for the segmentation and graph generation at the higher resolutions. We have applied our methods to MRI data sets of human brains. The hierarchical segmentation framework can be used for brain-mapping purposes.

6.3.2. Visualisation of large numerical simulation data sets

Participants: Georges-Pierre Bonneau, Stéphane Ploix, Fabien Vivodtzev.

This project is part of a collaboration with CEA/CESTA. CEA/CESTA has to perform numerical simulation on very large data sets, in thermodynamics, mechanics, aerodynamics, neutronics... Visualization of the results of these simulations is crucial in order to gain understanding of the phenomena that are simulated. The visualization techniques need to be interactive - if not real time, to be helpful for engineers. Therefore multiresolution techniques are required to accelerate the visual exploration of the data sets. We are developing multiresolution algorithms devoted to specific type of data sets. Our current focus is on volumetric data sets based on tetrahedral grids in which inner structures of dimension 2, 1 or 0 must be preserved, both geometrically and topologically. To maintain these important features during the multiresolution decomposition, techniques based on combinatorial topology have been developed. The first results concern the preservation of 1D and 0D structures in triangular grids. A publication has been submitted on this topic to the EG-IEEE Euro-Vis'05 conference. Figure 8 illustrates the preservation of polylines (in red) and specific points (in yellow) in a CAD/CAM mesh. The generalization of these results to the volumetric case is currently under investigation.

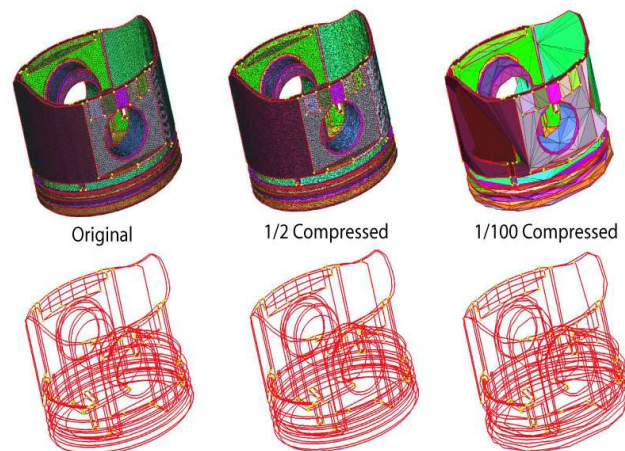


Figure 8. Preservation of polylines (in red) and specific points (in yellow) in a CAD/CAM mesh.

6.3.3. Perceptive Visualization

Participants: Georges-Pierre Bonneau, Stéphane Ploix.

This project is part of a collaboration with the research and development department of EDF, and with LPPA (Laboratoire de Physiologie de la Perception et de l'Action, Collège de France). The general context is similar to the collaboration with CEA (Section 6.3.2), i.e. the visualisation of large numerical data sets.

The focus in this project is on the following problem: How should human perception be taken into account in Visualization algorithms, and more specifically in algorithms based on multiresolution techniques? Previous works in this area are mostly based on image analysis techniques, that are used to measure important features in a static image resulting from some visualization algorithm. These results do not take into account information on the specific person using the visualization system. We are especially interested in taking into account such information, like for example the point where the user is looking at. Also we want to insert dynamic parameters in the perceptive measure, like the movement of the user's head, since such parameters greatly influence the actual perception of the rendered scene. In the framework of this collaboration, EDF will finance a PhD grant on these topics.

6.4. Efficient rendering of natural scenes

Participants: Florence Bertails, Marie-Paule Cani, Philippe Decaudin, Alexandre Meyer, Fabrice Neyret.

6.4.1. Volumetric representation using texcells

Participants: Philippe Decaudin, Fabrice Neyret.

In the scope of the Vertigo collaboration (RIAM funding, cf 7.1), we are extending our past work on realistic, real-time volumetric textures, the target being the management of forest covered scenery in virtual reality applications (see figure 9).

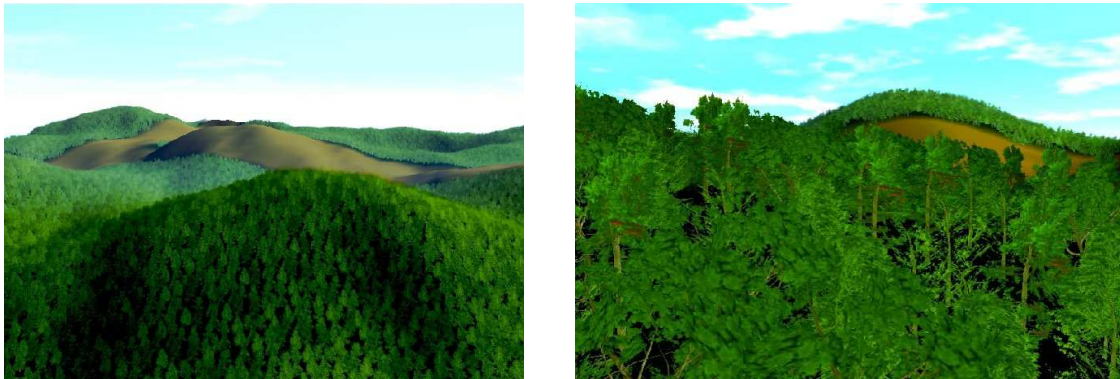


Figure 9. Real-time realistic forests using Volumetric textures (mixed together with Bionatics' hybrids).

We have developed a new representation allowing for the real-time rendering of realistic forests. It produces dense forests corresponding to continuous non-repetitive fields made of thousands of trees with full parallax. It draws on volumetric textures and aperiodic tiling: the forest consists of a set of edge compatible prisms containing forest samples which are aperiodically mapped onto the ground. The representation allows for quality rendering, thanks to appropriate 3D non-linear filtering. It relies on LODs and on a GPU-friendly structure to achieve real-time performance.

This resulted in a publication [15] at EGSR'04. Moreover, the Master thesis work of Florent Cohen on shading and shadowing the forest model with the GPU led to a poster [31] presented at Siggraph'04.

Concerning the Vertigo collaboration, a library combining our representation and the "hybrid" trees developed by Bionatics has been realised. It has been integrated in a prototype based on the professional training flight simulator developed by Thales Training and Simulation.

6.4.2. Adaptive surfels for real-time forest sceneries

Participants: Alexandre Meyer, Fabrice Neyret.

During his Master Thesis, Guillaume Gilet has developed an adaptive model of *surfels* (a point based representation): the size of points (i.e. discs) depends on the distance and on the visibility, and represent a set of leaves (these sets are organized hierarchically in that purpose). Moreover, surfels commute to classical meshes for close points of view. This allows for the interactive rendering of forests with both close and distant trees, and continuous flyovers of entire forests (see Figure 10).



Figure 10. Interactive forest rendering utilising surfels

6.4.3. Self shadowing of animated scenes

Participants: Florence Bertails, Marie-Paule Cani.

Self shadows are particularly important to get the adequate impression of volume for complex natural objects such as hair (see Figure 11). We just developed an efficient self shadowing method (submitted for publication) particularly well adapted to the rendering of animated objects, since it requires no geometry-based pre-computation. Our method is based on a 3D light-oriented density map, a novel structure that combines an optimized volumetric representation of hair with a light-oriented partition of space. Using this 3D map, accurate hair self-shadowing can be interactively processed (several frames per second for a full hairstyle) on a standard CPU. Beyond the fact that our application is independent of any graphics hardware (and thus portable), it can easily be parallelized for better performance. A parallel implementation makes the method run in real-time.

6.5. Procedural methods for geometry and motion

Participants: Marie-Paule Cani, Caroline Larboulette, Frank Perbet.

6.5.1. A generic tool for multi-resolution procedural modelling

Participants: Marie-Paule Cani, Frank Perbet.

Procedural modelling is probably the only approach enabling the modelling of a virtually infinite world with an unlimited number of details of different scales, that may be auto-similar or not. The last part of Frank Perbet's thesis [3], defended in February 2004, has proposed a generic tool, based on dynamic graphs, for the efficient on-fly generation and exploration of this kind of model. Only the parts of the scene which

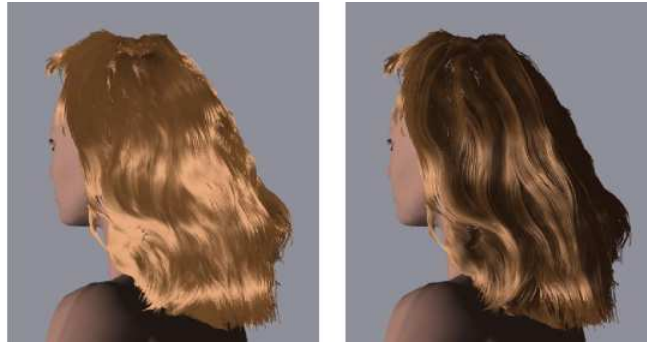


Figure 11. Hair rendering without (left) and with self shadows (right).

are currently visible are generated, at the adequate level of details, enabling real-time display even during interactive zooming operations.

6.5.2. Procedural skinning for character animation

Participants: Marie-Paule Cani, Caroline Larboulette.

Adding details to an animation while avoiding the heavy cost of a full physically-based simulation can be done through a procedural approach. We proposed a method of that kind for generating skin and cloth wrinkles on top of a standard character animation [20] : the dynamic wrinkles layer (see Figure 12) uses the deformations of the underlying mesh together with constraints such as length preservation for generating local deformations mimicking wrinkles. Results are generated in real-time. In her thesis [2] defended in November 2004, Caroline Larboulette combines this method with a simple dynamic layer which adds dynamic vibrations to the flesh of the character, under quick skeleton motion.

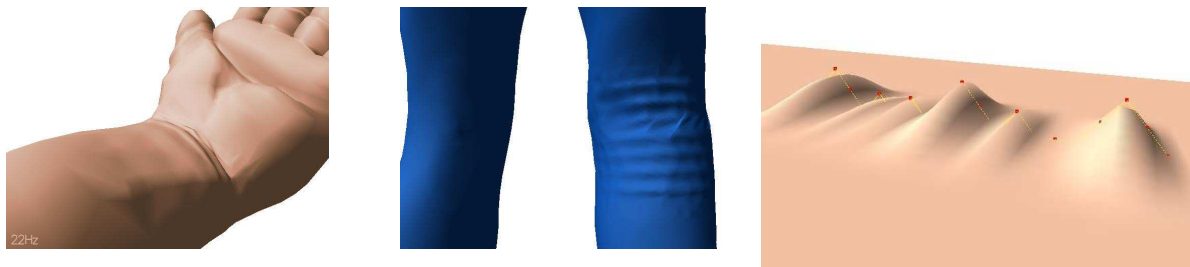


Figure 12. Skin and cloth wrinkles generated with a dynamic wrinkles layer

6.6. Physically-based simulation

Participants: Florence Bertails, Marie-Paule Cani, Jean Combaz, Mathieu Coquerelle, Guillaume Dewaele, François Faure, Olivier Galizzi, Thanh Giang, Matthieu Nesme, Fabrice Neyret, Laks Raghupathi, Florence Zara.

6.6.1. Morphogenesis, expansion textures

Participants: Jean Combaz, Fabrice Neyret.

The purpose is to offer a modeling tool for complex surfaces whose shape results from growing phenomena (e.g. biological or geological surfaces), by allowing the user to control the growth rather than the shape itself. Control is achieved through a texture encoding of the intensity and orientation of the deformations, either explicitly (e.g. map of rifts and subductions) or generatively (e.g. reticulation, hot spots). Moreover, the control can also be interactive by ‘painting’ the effects directly onto the surface (see figure 13). This approach allows an artist to produce folded shape using a workflow close to sculpting, while it may be difficult to obtain such shapes using a physical simulator: The initial state and the history of forces is often unknown or not easily modeled (e.g. for an unmade bed).

Jean Combaz has defended his PhD on Expansion Textures [1]. A poster [26] was presented at SCA’04.

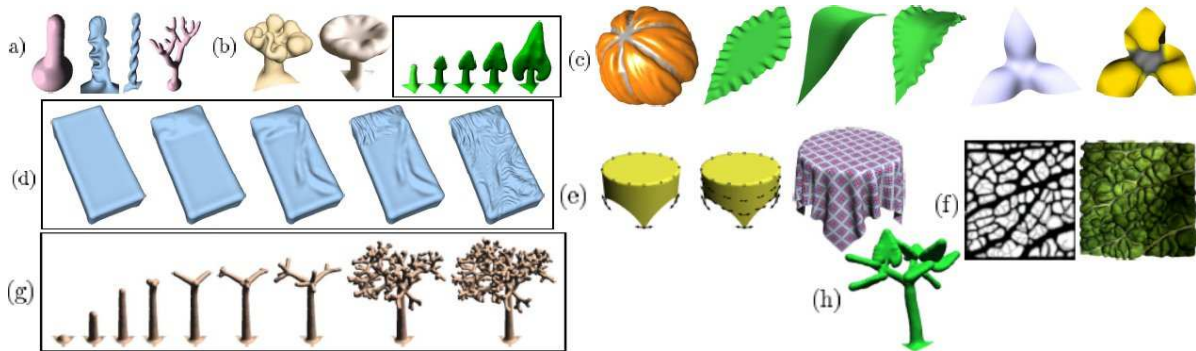


Figure 13. Complex surfaces obtained using pre-drawn or interactively controlled expansion textures. Framed images correspond to animations. a,b,c: 0D (hot spot), 1D (hot curves) and 2D interactive expansion primitives. d,e: interactive pseudo-simulations. f: expansion controlled by a texture image. g,h: expansion controlled by an automata.

6.6.2. Virtual clay

Participants: Marie-Paule Cani, Guillaume Dewaele.

Efficiently animating virtual clay is a challenge, since neither optimisations proposed for solids (and based on a constant topology) nor for fluids (since there is a moving limit surface) are directly applicable. We, thus, proposed the first real-time model for this material [4], based on a layered approach. Three sub-models respectively handling large-scale deformations, local matter displacements, and surface tension, cooperate over time for providing the desired behaviour. Our model has been recently extended to handle an arbitrary number of tools that simultaneously interact with the clay [17]. This makes the model usable for direct hand manipulation, which is the last step in Guillaume Dewaele’s thesis: the user’s motion is video captured and used to control a virtual hand that serves as a multiple tool for editing the clay.

6.6.3. Adaptive deformation fields

Participants: Mathieu Coquerelle, François Faure, Thanh Giang.

The aim of this research is to develop novel methods for the representation and physical simulation of variations in highly deformable mesh structures for real-time animation (e.g. from the simulation of cloth to virtual surgery) through a level of detail (lod) topological approach. The research currently concentrates on the use of two primary hierarchical data structures, these being the octree and quadtree, for managing the changing multiresolution detail as well as the physical property details of mesh structures such as the likes of cloth during simulation (see Figure 14).

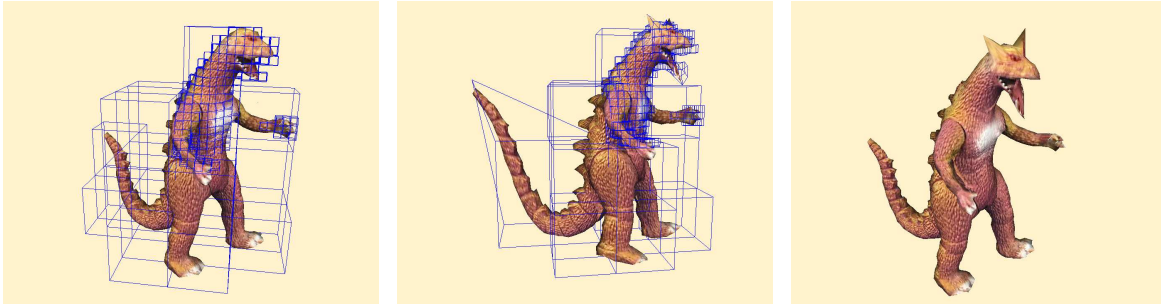


Figure 14. Direct manipulation of a 3D model through a deformable octree data structure

One of the primary ideas of this research is to be able to effectively use either data structure not only as a possible multiresolution paradigm for on the fly lod mesh generation during animation but also to integrate such data structures directly within the manipulation and management of the physical properties of the mesh as well. For example, collision detection could also simultaneously be handled directly through the same data structure which manages the current local mesh resolution, thus negating the necessity of a secondary data structure for such a task.

6.6.4. Physically-based interactive rigid bodies

Participants: François Faure, Olivier Galizzi.

We are currently working with our partners of laboratory 3S on the software integration of several rock modeling, collision detection, and mechanical response computation methods for purposes of exhaustivity and fair comparison.

6.6.5. Highly colliding deformable bodies

Participants: Marie-Paule Cani, François Faure, Matthieu Nesme, Laks Raghupathi.

We address the question of simulating highly deformable objects in real-time, such as human tissues or cloth. The main problem is to detect and handle multiple (self-)collisions within the bodies. We develop a new approach for collision detection, based on a pool of "active pairs" of geometric primitives. These pairs are randomly chosen, and they iteratively converge to a local distance minimum or to a pair of colliding elements. Managing the size of the pool allows us to tune the computation time devoted to collision detection. Temporal coherence is obtained by reusing the interesting pairs from one step to another.

The application of this approach to virtual surgery has been further investigated [5][7].

We have used this method in conjunction with hierarchical bounding volumes. This allows us to directly discard all the active pairs which do not belong to a pair of colliding bounding volumes. An application to virtual cloth simulation (see Figure 15) has been shown [19].

Beside this, we have contributed to a survey on the domain of collision detection for deformable objects [23].

6.6.6. Robust finite elements for deformable solids

Participants: François Faure, Matthieu Nesme.

We have started a collaboration on surgical simulation with laboratory TIMC through a co-advised Ph.D. thesis. The purpose is to develop new models of finite elements for the interactive physically-based animation of human tissue. A new model of tetrahedron-based finite elements has been proposed [34]. Its main feature is to remain physically plausible even when large displacements and large deformations occur (see Figure 16), while being almost as computationally efficient as a linear finite elements method.

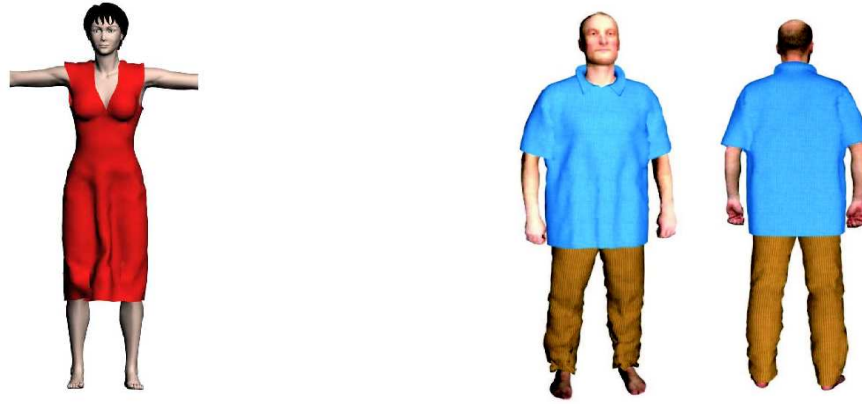


Figure 15. Virtual cloth simulation with stochastic collision detection

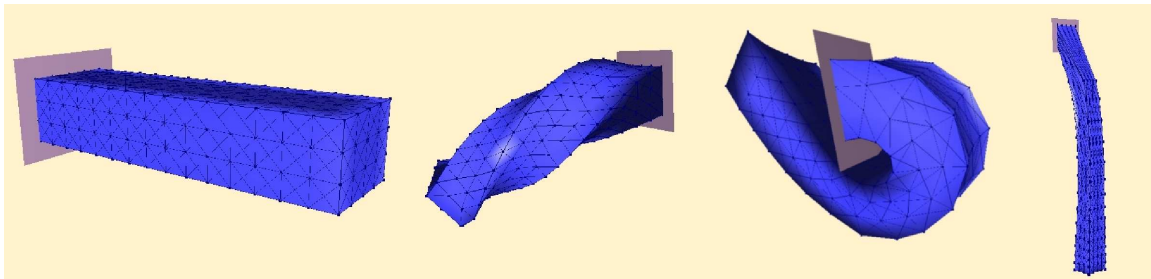


Figure 16. Stable large deformations produced through a robust tetrahedron-based finite elements approach

6.6.7. *Parallel simulation of cloth*

Participants: François Faure, Florence Zara.

We addressed the question of simulating cloth on a PC cluster, in collaboration with laboratory ID and company Yxendis. Cloth is modeled as a physically-based deformable mesh. There are two important difficulties:

- To reduce the amount of communication between the cluster nodes;
- To transfer the data from the cluster to the display machine.

We split the cloth in compact pieces, thus reducing communication to data related to the borders of the patches. We use socket communications to transfer the data scattered in the cluster to the display machine. We have concluded this work [9] and we are currently working on a new distribution platform with our partners of laboratory ID.

6.6.8. *Hair simulation*

Participants: Florence Bertails, Marie-Paule Cani.

The adaptive model for interactive hair animation we had developed in the past few years was far from taking into account the mechanical properties of inextensible, naturally curled hair strands. We are currently investigating a way of simulating more accurate hair mechanics [30]. At the other end of the spectrum, we have developed a robust, real-time hair model for a virtual reality experiment [28].

6.7. *Motion capture from video*

Participants: Fabien Dellas, Laurent Favreau, Alexandre Perrin, Lionel Reveret.

This research project aims at capturing motion from the automatic processing of video to provide information for 3D animation of characters, such as humans or animals. Unlike several approaches in computer vision research, the goal is not to recognize activities, but rather to acquire robust geometric hints to control animation. Three main projects are currently under investigation: facial animation, deformation of skin surface and motion of animals.

6.7.1. *Motion capture of facial expression*

Participants: Alexandre Perrin, Lionel Reveret.

Previous results showed that 3D animation of facial expression can be described with a compact set of linear modes. This parametric reduction guarantees robustness when applied to the tracking of facial motion from video. However, it does not take into account the motion due to expressions such as smiling. The goal of this project is to combine several methods of facial animation into a coherent framework. As preliminary results, a method has been implemented to allow integration between linear models for speech production and pseudo-muscles models for expressions (see section 7.3).

In order to allow the processing of large video data such as video documentaries or video streaming from a webcam, previous works on motion capture have been adapted to be computed on GPU. This has implied a reformulation of the algorithms so that the approach could be implemented on the specific architectures of pixel shaders.

6.7.2. *Motion capture of animal motion*

Participants: Laurent Favreau, Lionel Reveret.

The motion of animals is still a challenging problem in 3D animation, both for articulated motion and deformation of the skin and fur (see Figure 17). The goal of this project is to acquire information from the numerous video footage of wild animals. These animals are impossible to capture into a standard framework of motion capture with markers. There are several challenges in the usage of such video footage for 3D motion capture : only one 2D view is available, important changes occur in lighting, contrast is low between the

animal and foreground, etc. Currently, a method has been developed to first extract a binary silhouette of the animals and then, to map this silhouette to pre-existing 3D models of animals and motion thanks to a statistical prediction.

This work has been published at the Symposium on Computer Animation 2004 (SCA'04) [18]. It will be continued in collaboration with the University of Washington at Seattle.

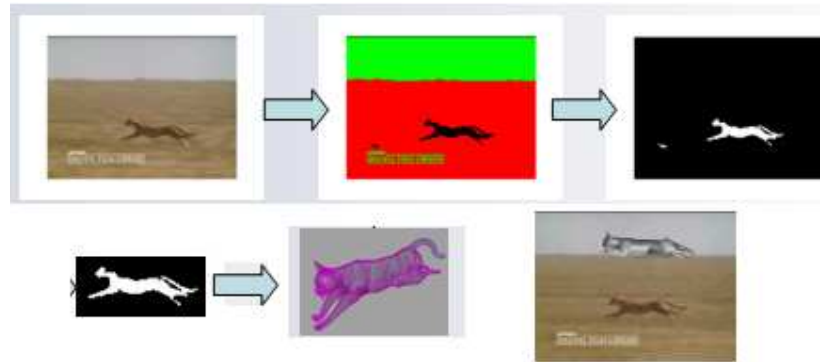


Figure 17. Motion capture of animal motion

6.7.3. Motion capture of skin and muscles motion

Participants: Fabien Dellas, Lionel Reveret.

The modeling of precise deformation of skin due to muscles and bones motion is still challenging. In order to accurately extract the 3D motion of the skin, a dedicated suit has been built. It consists of stretchy fabric textures with a regular checker board pattern. The recording under three different viewpoints allows to reconstruct in 3D the surface of the skin during a bulging of the muscle for example. One of the contributions has been also to show that statistical criteria could be determined to evaluate if the tracking of the surface is giving non reliable results. This preliminary work has been published at the Workshop on Modelling and Motion Capture Techniques for Virtual Environments [16].

6.8. Applications covered by this year's results

The above sections presented our research in terms of fundamental tools, models and algorithms. A complementary point of view is to describe it in terms of application domains. The following sections describe our contribution to each of these domains, with reference to the tools we relied on if they were already presented above.

6.8.1. Interactive modelling systems

Participants: Alexis Angelidis, Georges-Pierre Bonneau, Marie-Paule Cani, Guillaume Dewaele, Alex Yvart.

Several of the tools we are developing are devoted to a new generation of interactive modelling systems:

- The multi-resolution subdivision surfaces presented in section 6.1.2 have been used for interactive multi-resolution modelling.
- The space deformations developed by our external collaborator Alexis Angelidis (see section 6.1.4), and in particular the extension to constant volume deformations are used for intuitive geometric editing of shapes of a constant topological genus.

- The *expansion textures* developed by Jean Combaz (see section 6.6.1) aim at offering high or middle-level tools to graphics users to design complex shapes such as wrinkles and folds.
- The real-time physically-based model for virtual clay presented in section 6.6.2 is dedicated to a sculpting system as close as possible to interaction with real-clay: in the context of Guillaume Dewaele's thesis, co-advised by Radu Horaud from the MOVI group, the virtual clay model is currently being combined with a vision interface for capturing the motion of the user's hands. So our clay model will be directly sculpted by fingers, making it usable for any artist, or even as an educational tool for small children.

6.8.2. *Synthesis of natural sceneries*

Participants: Philippe Decaudin, François Faure, Sylvain Lefebvre, Alexandre Meyer, Fabrice Neyret, Frank Perbet.

The diverse fundamental tools we are developing can be combined to allow the large scale specification (see section 6.2.2), efficient rendering (see sections 6.4.1, 6.5.1) and animation of vegetation (prairies, trees, forest, etc). These elements are currently used in the Vertigo project, enabling industrial transfer of our research results (see section 7.1).

Lastly, the specification of complete natural sceneries is one of the aims of the Dereve II project (see section 8.1.1).

6.8.3. *Medical applications*

Participants: Marie-Paule Cani, François Faure, Olivier Palombi, Laks Raghupathi.

Some of our work on geometric modelling and physically-based animation has been successfully applied to the medical domain:

Our tools for efficient physically-based simulation, and in particular our new contributions to collision detection and response (see section 6.6.5), will be used in a new European medical project called *Odysseus* (see section 8.3.2).

Furthermore, Mathieu Nesme's PhD research (see section 6.6.6), which is co-advised by Yohan Payam of laboratory TIMC, concentrates on the development of improved models for human tissue simulation for surgical simulations.

6.8.4. *Animation of virtual creatures*

Participants: Florence Bertails, Marie-Paule Cani, Christine Depraz, François Faure, Laurent Favreau, Caroline Larboulette, Alexandre Perrin, Lionel Reveret.

Several of our new models and algorithms contribute to the animation of virtual creatures. This includes our work on motion capture from video (general body motion, faces, and body deformations, see section 6.7); the procedural method we developed for adding skin details (see section 6.5.2); the physically-based animation tools (sections 6.6.5 and 6.6.7) that we are currently applying to the simulation of virtual garments; and our adaptive animation algorithm for efficiently computing hair motion (see 6.6.8).

Except for the extraction of an animal's global motion from video, all of these contributions are developed within projects with industrial partners (see Virtual Actors RIAM project section 7.3 and RNTL PARI project section 7.2).

A first work towards the perceptive evaluation of animation has been achieved in collaboration with the dept. of Psychology of the U. of Geneva for facial animation. A study has been made to evaluate what different parts of the brain are activated when a picture of an expressive face is showed to a subject, with gaze pointing towards the subject or not. It has been necessary to adapt a 3D model to standard photographs of expressive faces, so that the eye orientation on the photographs could be accurately controlled in a realistic manner. The results of this study have been published at the Annual Conference of Neuroscience 2004 [22] and to the European Journal of Neurosciences [6].

7. Contracts and Grants with Industry

7.1. RIAM Vertigo

Participants: Philippe Decaudin, Fabrice Neyret.

The partners of this collaboration are Bionatics (developer of softwares dedicated to the creation of 3D models of plants for image production and video games), Thales Training & Simulation (flight simulators) and EVASION. The project is funded (115000 euros for Evasion) by the CNC (Centre National de la Cinématographie) and RIAM (Réseau pour la Recherche et l'Innovation en Audiovisuel et Multimédia) for 18 months and started in February 2003. The purpose is to extend and transfer our representations and techniques of realistic real-time rendering of a forest. An engineer and a student (to date) are specifically working on this.

7.2. RNTL PARI

Participants: Marie-Paule Cani, François Faure, Caroline Larboulette, Laks Raghupathi.

The goal of this collaboration with company Galilea is to develop tools for easily including physically-based animation in video games, especially for more realistic humanoids. We transfer our technology for interactive skin and cloth simulation.

7.3. RIAM Virtual Actors

Participants: Florence Bertails, Marie-Paule Cani, Alexandre Perrin, Lionel Reveret.

In the context of a RIAM contract started in June 2003 for 18 months with Galilea and LEIBNIZ/INPG, new technological tools are currently being developed for the creation of believable 3D characters for video games. EVASION is involved in two main projects : facial animation for talking characters and real-time animation of hair.

7.4. Collaboration with ATI and Nvidia Graphics board constructors

Participants: Philippe Decaudin, François Faure, Sylvain Lefebvre, Alexandre Meyer, Fabrice Neyret, Frank Perbet, Lionel Reveret.

We are still in close contact with the ATI and Nvidia development teams providing suggestions and bug reports, and testing prototype boards.

7.5. Collaboration with Alias|Wavefront

Participants: Christine Depraz, Alexandre Perrin, Lionel Reveret.

The licences granted to EVASION by Alias|Wavefront for their 3D modeling and animation software Maya in the context of a research agreement is still retained for 2004. Maya is still currently used to edit and visualise animations of animal motion and facial animation. Another project explores the use of Maya as a graphical front end for a 3D modeling tool from hand gestures.

8. Other Grants and Activities

8.1. Regional projects

8.1.1. Rhône-Alpes Project: Dereve II

Participants: Marie-Paule Cani, Alexandre Meyer.

This is a regional project in the domain of Computer Graphics started in July 2003 for one year, where EVASION has been involved on two points. First, on the morphing of textured models: collaboration between Marie-Paule Cani and Eric Galin (LIRIS). Second, on the modelling and rendering of the Alpine landscapes:

collaboration between Alexandre Meyer, Eric Tosan (LIRIS) and Xavier Marsault (Ecole d'Architecture de Lyon).

8.2. National projects

8.2.1. ARC Docking

Participant: Georges-Pierre Bonneau.

The partners within INRIA for this collaboration are ISA (INRIA-Nancy research unit), GEOMETRICA (INRIA-Sophia-Antipolis research unit) and EVASION. This two year project has ended in December 2004. The original main objective of developing an immersive, interactive and easy-to-use modelling environment to enhance molecular docking has been fully reached. Two plug-ins for the standard software VMD (Visualization of Molecular Dynamics) have been successfully developed, and several papers have been published on this topic by the participants of the ARC Docking.

8.2.2. CNRS AS Virtual Human

Participants: Florence Bertails, Marie-Paule Cani, Caroline Larboulette, Alexandre Perrin, Lionel Reveret.

This project (from October 2003 to October 2004) is an initiative from C. Pelachaud (U. Paris VIII), S. Donikian (SIAMES project, IRISA) and J.P. Jessel (IRIT) to gather state-of-the-art and perspective on the modelling and animation of 3D character animation among the French research community. In particular, the members of EVASION are participating in two groups : Modelling of the human body, lead by S. Akkouche (LIRIS), and Conversation Agents, lead by C. Pelachaud (U. Paris VIII).

8.2.3. Robea "Modèles Bayésiens pour la Génération de Mouvement"

Participants: François Faure, Olivier Galizzi.

The partners for this project are the E-MOTION group at GRAVIR and the SIAMES group at IRISA (Rennes). The goal of this project is to model the behavior of autonomous characters in complex environments. Our contribution is to model a vegetation scene and to simulate uneven ground with local collapses under the feet of the characters.

8.3. European projects

8.3.1. Network of excellence Aim@Shape

Participants: Alexis Angelidis, Georges-Pierre Bonneau, Marie-Paule Cani, Frank Hétry, Basile Sauvage, Alex Yvart.

The mission of AIM@SHAPE is to advance research in the direction of semantic-based shape representations and semantic-oriented tools to acquire, build, transmit, and process shapes with their associated knowledge. We foresee a new generation of shapes in which knowledge is explicitly represented and, therefore, can be retrieved, processed, shared, and exploited to construct new knowledge. This Network of Excellence started in December 2003. This year Georges-Pierre Bonneau and Marie-Paule Cani have actively collaborated in the publication of STAR reports on the topics covered by the Network. Georges-Pierre Bonneau has participated a Network Meeting in Santorini dedicated to Knowledge-based systems, and has co-organized a Network meeting in Grenoble.

8.3.2. Odysseus

Participants: Marie-Paule Cani, François Faure, Laks Raghupathi.

Odysseus is a European project on the simulation of laparoscopic surgery. Driven by IRCAD, it involves two industrial partners (Karl Storz, SimSurgery) and three research projects of INRIA (EVASION, EPIDAURE, ALCOVE). The overall project is to develop several commercial products over the next three years. Our participation is related to planning and real-time simulation using patient-specific data.

9. Dissemination

9.1. Leadership within the international scientific community

Marie-Paule Cani contributed to the creation of a French chapter for the Eurographics association in July 2003. She has been the president of this chapter since then. The second event of the French chapter is the conference "Rencontres Francophones d'Informatique Graphique" held in Poitiers in November 2004, jointly with AFIG (Association Française d'Informatique Graphique).

9.2. Editorial boards and program committee

Program Committees:

- Marie-Paule Cani served as "Program chair" for Eurographics Graphics 2004. She was a program committee member for "Shape Modeling International" (SMI'04, Genova, Italy, 7-9 June 2004) and is program co-chair for the upcoming SMI'05 (Massachusetts, USA, 13-17 June 2005). She also served on the steering committee as well as being a program committee member for "ACM Symposium on Computer Animation" (SCA'04, Grenoble, France).
- Georges-Pierre Bonneau was a program committee member for "Shape Modelling International 04" (SMI'04, Genova, Italy, 7-9 June 2004) and continues to remain a program committee member for SMI'05 (Massachusetts, USA, 13-17 June 2005). As well as this, he was also a program committee member for "Eurographics Symposium on Parallel Graphics and Visualisation" (Grenoble, 10-11 June 2004), IEEE Visualization'04 (Austin, Texas, October 10-15 2004) and EG-IEEE Visualization Symposium'04 (Konstanz, Germany, May 19-21 2004). He was a senior reviewer for Eurographics 2004 (Grenoble, France, 30 August-3 September 2004).
- François Faure served on the international program committee for "Computer Animation and Social Agents" (CASA'04, Geneva, Switzerland).
- Lionel Reveret was the "Local Organisation chair" for "ACM Symposium on Computer Animation" (SCA'04, Grenoble, France). He was also a program committee member of the posters session at SIGGRAPH'04 (Los Angeles, USA, 10-12 August 2004) and a member of the best paper committee of AFIG'04 (Poitiers, France).
- Fabrice Neyret was a program committee member for "ACM Symposium on Computer Animation" (SCA'04, Grenoble, France), and part of the local organising committee of Eurographics 2004 (Grenoble, 30 August-3 September 2004).

Editorial boards:

Marie-Paule Cani serves in the editorial board of the journal Graphical Models (academic press); Georges-Pierre Bonneau serves in the editorial board of the IEEE TVCG journal.

9.3. Invited conferences

The EVASION team members have also given several invited talks in addition to their involvement in the many aforementioned conferences and workshops during the year. Marie-Paule Cani gave two invited talks during the year; one at the “Graphics Lunch” of ETHZ in Zurich in February 2004 and the other at DGP at the university of Toronto in July 2004.

Caroline Larboulette gave a talk at the Institute of Computer Graphics and Algorithms, Vienna University of Technology towards the end of October 2004 on her PhD research on "Real-Time Processing of the Deformations of Skin and Sub-cutaneous Tissues for Character Animation".

Lionel Reveret has been invited to present his works on 3D animation of animals to a Symposium dedicated to Etienne-Jules Marey at the College de France in Paris.

9.4. Large public conferences and meetings

- Active participation of the team to the national day of science "Science en Fête" with a dedicated virtual reality demo (monitorat project shared by several teams) [28], and video demonstration presenting an overview of our work to a large audience.
- Fabrice Neyret is member of the “Cafés Sciences et Citoyen” animation team (Grenoble), funded by the communication department of CNRS, and he maintains the web site <http://www-evasion.imag.fr/cafesSC/>. Conferences are organised on a monthly basis.
- Marie-Paule Cani gave a talk on the medical applications of CG and Virtual Reality at the "Midi-sciences" conference in Grenoble.
- The 'MobiNet' team (4 members of Artis and Evasion including a "monitorat" project plus a dozen of temporary assistants) organizes 8 practices per year on a half-day basis for about 150 senior high school students in the scope of INPG "engineer weeks". The purpose is to give a more intuitive practice of math and physics, and to give insights on programming and engineering. See 5.4 and <http://www-evasion.imag.fr/mobinet/>.
A paper [21] was published in Eurographics-education, and a communication was presented at the national seminar “le goût des Sciences”.
- Many EVASION team members were actively involved in helping with various organisational aspects for international conferences that were hosted in Grenoble during 2004. Most notably, Florence Bertails and Olivier Galizzi volunteered time during the year to help Lionel Reveret (who was local organisation chair) in various aspects of the organisation and ensurance of the smooth running of the “ACM Symposium on Computer Animation” (SCA'04). Similarly, Laks Raghupathi and Thanh Giang also volunteered time to help Jean-Dominique Gascuel of team ARTIS with various organisational aspects for the Eurographics 2004 conference.

9.5. Teaching

In addition to the regular teaching activities (UJF, INPG) of the faculty members, several researchers at EVASION taught some courses to the "Image, Vision, Robotics" Master Research, the "Mathematic Engineering" Master and to the 3rd year "Image and Virtual Reality" of ENSIMAG. François Faure gave a course on animation at the Vienna University (Austria) during 2 weeks (22 hours).

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