IN PARTNERSHIP WITH:
**CNRS**

**Institut polytechnique de Grenoble**

**Université Joseph Fourier (Grenoble 1)**

# Activity Report 2011

# Project-Team ARTIS

# Acquisition, representation and transformations for image synthesis

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
**Grenoble - Rhône-Alpes**

THEME
**Interaction and Visualization**

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# Project-Team ARTIS

**Keywords:** 3D Modeling, Computer Graphics, Rendering, Visualization

*ARTIS is both an INRIA project-team and a subset of the LJK (UMR 5224), a joint research lab of CNRS, Université Joseph Fourier Grenoble-I (UJF), Université Pierre Mendès France Grenoble II (UPMF) and Institut National Polytechnique de Grenoble (INPG).*

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Imma Presseguer

# 2. Overall Objectives

## 2.1. Overall Objectives

ARTIS was created in January, 2003, based on the observation that current image synthesis methods appear to provide limited solutions for the variety of current applications. The classical approach to image synthesis consists of separately modeling a 3D geometry and a set of photometric properties (reflectance, lighting conditions), and then computing their interaction to produce a picture. This approach severely limits the ability to adapt to particular constraints or freedoms allowed in each application (such as precision, real-time, interactivity, uncertainty about input data...). Furthermore, it restricts the classes of possible images and does not easily lend itself to new uses such as illustration, where a form of hierarchy of image constituents must be constructed.

One of the goals of the project is the definition of a more generic framework for the creation of synthetic images, integrating elements of 3D geometry, of 2D geometry (built from 3D geometry), of appearance (photometry, textures...), of rendering style, and of importance or relevance for a given application. The ARTIS project-team therefore deals with multiple aspects of image synthesis: model creation from various sources of data, transformations between these models, rendering and imaging algorithms, and the adaptation of the models and algorithms to various constraints or application contexts. The main research directions in ARTIS address:

- Analysis and simulation of lighting effects. Development of hierarchical simulation techniques integrating the most general and realistic effects, fast rendering, inverse lighting, relighting, data acquisition based on lighting analysis.
- Expressive ("non-photorealistic") rendering. Definition and identification of rendering styles. Style extraction from existing documents. Development of new view models (mixture of 3D and 2D) and new rendering techniques.
- Model simplification and transformation. Simplification of geometry and appearance, image-based representations, model transformation for various applications, detail creation and creation of virtual models from real data.

Our target applications are dealing with 3D image synthesis, radiative transfer simulation, visualization, virtual and augmented reality, Illustration and computational photography. As application domains we are working on video games, animation movies, technical illustration, virtual heritage, lighting design, rehabilitation after a traumas...

# 3. Scientific Foundations

## 3.1. Introduction

The objectives of ARTIS combine the resolution of "classical", but difficult, issues in Computer Graphics, with the development of new approaches for emerging applications. A transverse objective is to develop a new approach to synthetic image creation that combines notions of geometry, appearance, style and priority.

## 3.2. Lighting and Rendering

**Participants:** Mahdi Bagher, Cyril Crassin, Isabelle Delore, Olivier Hoel, Nicolas Holzschuch, Fabrice Neyret, Charles de Rousiers, Cyril Soler.

Glossary

**Global illumination** Complete set of lighting effects in a scene, including shadows and multiple reflections or scattering

**Inverse rendering** Calculation process in which an image formation model is inverted to recover scene parameters from a set of images

The classical approach to render images of three-dimensional environments is based on modeling the interaction of light with a geometric object model. Such models can be entirely empirical or based on true physical behavior when actual simulations are desired. Models are needed for the geometry of objects, the appearance characteristics of the scene (including light sources, reflectance models, detail and texture models...) and the types of representations used (for instance wavelet functions to represent the lighting distribution on a surface). Research on lighting and rendering within ARTIS is focused on the following two main problems: lighting simulation and inverse rendering.

### *3.2.1. Lighting simulation*

Although great progress has been made in the past ten years in terms of lighting simulation algorithms, the application of a general global illumination simulation technique to a very complex scene remains difficult. The main challenge in this direction lies in the complexity of light transport, and the difficulty of identifying the relevant phenomena on which the effort should be focused.

The scientific goals of ARTIS include the development of efficient (and "usable") multi-resolution simulation techniques for light transport, the control of the approximations incurred (and accepted) at all stages of the processing pipeline (from data acquisition through data representation, to calculation), as well as the validation of results against both real world cases and analytical models.

#### *3.2.1.1. Image realism*

There are two distinct aspects to realism in lighting simulation: First the physical fidelity of the computed results to the actual solution of the lighting configuration; Second the visual quality of the results. These two aspects serve two different application types: physical simulation and visually realistic rendering.

For the first case, ARTIS' goal is to study and develop lighting simulation techniques that allow incorporation of complex optical and appearance data while controlling the level of approximation. This requires, among other things, the ability to compress appearance data, as well as the representation of lighting distributions, while ensuring an acceptable balance between the access time to these functions (decompression) which has a direct impact on total computation times, and memory consumption.

Obtaining a *visually* realistic rendering is a drastically different problem which requires an understanding of human visual perception. One of our research directions in this area is the calculation of shadows for very complex objects. In the case of a tree, for example, computing a visually satisfactory shadow does not generally require an exact solution for the shadow of each leaf, and an appropriately constrained statistical distribution is sufficient in most cases.

#### *3.2.1.2. Computation efficiency*

Computation efficiency practically limits the maximum size of scenes to which lighting simulation can be applied. Developing hierarchical and instantiation techniques allows us to treat scenes of great complexity (several millions of primitives). In general the approach consists in choosing among the large amount of detail representing the scene, those sites, or configurations, that are most important for the application at hand. Computing resources can be concentrated in these areas, while a coarser approximation may be used elsewhere.

Our research effort in this area is two-fold: first we develop new algorithms for a smarter control of variance in Monte-Carlo algorithms, hence reducing the total cost at equivalent accuracy; secondly, we develop algorithms that specifically suit a GPU implementation, which brings us a huge gain in performance at the expense of controlled approximations.

#### *3.2.1.3. Characterization of lighting phenomena*

One of the fundamental goals of ARTIS is to improve our understanding of the mathematical properties of lighting distributions (*i.e.* the functions describing light "intensity" everywhere). Some of these properties are currently "known" as conjectures, for instance the unimodality (existence of a single maximum) of the light distribution created by a convex light source on a receiving surface. This conjecture is useful for computing error bounds and thus guiding hierarchical techniques. Other interesting properties can be studied by representing irradiance as convolution splines, or by considering the frequency content of lighting distributions. We also note that better knowledge and characterization of lighting distributions is beneficial for inverse rendering applications as explained below.

### *3.2.2. Inverse rendering*

Considering the synthetic image creation model as a calculation operating on scene characteristics (viewing conditions, geometry, light sources and appearance data), we observe that it may be possible to invert the process and compute some of the scene characteristics from a set of images.

This can only be attempted when this image calculation process is well understood, both at the theoretical level and at a more practical level with efficient software tools. We hope that the collective experience of lighting simulation and analysis accumulated by members of the project will guide us to develop efficient and accurate inverse rendering techniques: instead of aiming for the most general tool, we recognize that particular application cases involve specific properties or constraints that should be used in the modeling and inversion process.

Example applications include the reconstruction of 3D geometry by analyzing the variations of lighting and/or shadows, or the characterization of a light source from photographs of a known object.

## 3.3. Expressive rendering

**Participants:** Pierre Bénard, Georges-Pierre Bonneau, Pierre-Edouard Landes, Cyril Soler, Joëlle Thollot.

There is no reason to restrict the use of computers for the creation and display of images to the simulation of real lighting. Indeed it has been recognized in recent years that computer processing opens fascinating new avenues for rendering images that convey particular views, emphasis, or style. These approaches are often referred to as “non-photorealistic rendering”, although we prefer the term “expressive rendering” to this negative definition.

A fundamental goal of ARTIS is to propose new image creation techniques that facilitate the generation of a great variety of images from a given scene, notably by adapting rendering to the current application. This involves, in particular, significant work on the notion of *relevance*, which is necessarily application-dependent. Relevance is the relative importance of various scene elements, or their treatment, for the desired result and it is necessary to define relevance both qualitatively and quantitatively. Examples of specific situations may include rendering specular effects, night-time imagery, technical illustration, computer-assisted drawing or sketching, etc. The notion of relevance will also have to be validated for real applications, including virtual reality settings.

Another research direction for expressive rendering concerns *rendering styles*: in many cases it should be possible to define the constitutive elements of styles, allowing the application of a given rendering style to different scenes, or in the long term the capture of style elements from collections of images.

Finally, since the application of expressive rendering techniques generally amounts to a visual simplification, or abstraction, of the scene, particular care must be taken to make the resulting images consistent over time, for interactive or animated imagery.

## 3.4. Computational Photography

**Participant:** Cyril Soler.

Computational Photography refers to techniques that aim at improving the capabilities of digital photofraphy. It has become a really hot research topic which lies at the intersection of illumination computation, vision and expressive rendering. These techniques may be used to enhance images in several ways. application examples include image restauration, automatic colorization, relighting or tone mapping. The ARTIS team is thus naturally attracted to this area.

## 3.5. Guiding principles

We base our research on the following principles:

### *3.5.1. Mathematical and geometrical characterization of models and algorithms*

In all our target applications, it is crucial to control the level of approximation, for instance through reliable error bounds. Thus, all simplification techniques, either concerning geometry or lighting, require a precise mathematical analysis of the solution properties.

### *3.5.2. Balance between speed and fidelity*

We seek to develop representations affording a controllable balance between these conflicting goals. In particular this applies to multi-resolution techniques, where an appropriate generic process is defined, that can then be applied to “well chosen” levels of the hierarchy. This aspect is of course key to an optimal adaptation to the chosen application context, both for lighting simulations of geometric transformations and for simplification.

### *3.5.3. Model and parameter extraction from real data*

Modeling geometric shapes, appearance data and various phenomena is the most tedious task in the creation process for virtual scenes. In many cases it can be beneficial to analyze real documents or scenes to recover relevant parameters. These parameters can then be used to model objects, their properties (light sources, reflectance data...) or even more abstract characteristics such as rendering styles. Thus this idea of parameter extraction is present in most of our activities.

### *3.5.4. User friendliness*

In all our applications we try to keep in mind the role of the final user in order to offer intuitive controls over the result. Depending on the targeted goal we seek a good compromise between automation and manual design. Moreover we put the user into the research loop as much as possible via industrial contracts and collaboration with digital artists.

# 4. Application Domains

## 4.1. Illustration

Although it has long been recognized that the visual channel is one of the most effective means for communicating information, the use of computer processing to generate effective visual content has been mostly limited to very specific image types: realistic rendering, computer-aided cell animation, etc.

The ever-increasing complexity of available 3d models is creating a demand for improved image creation techniques for general illustration purposes. Recent examples in the literature include computer systems to generate road maps, or assembly instructions, where a simplified visual representation is a necessity.

Our work in expressive rendering and in relevance-guided rendering aims at providing effective tools for all illustration needs that work from complex 3d models. We also plan to apply our knowledge of lighting simulation, together with expressive rendering techniques, to the difficult problem of sketching illustrations for architectural applications.

## 4.2. Video games and visualization

Video games represent a particularly challenging domain of application since they require both real-time interaction and high levels of visual quality. Moreover, video games are developed on a variety of platforms with completely different capacities. Automatic generation of appropriate data structures and runtime selection of optimal rendering algorithms can save companies a huge amount of development (*e.g.* the EAGL library used by Electronic Arts [33]).

More generally, interactive visualization of complex data (e.g. in scientific engineering) can be achieved only by combining various rendering accelerations (e.g. visibility culling, levels of details, etc.), an optimization task that is hard to perform “by hand” and highly data dependent. One of ARTIS’ goals is to understand this dependence and automate the optimization.

## 4.3. Virtual heritage

Virtual heritage is a recent area which has seen spectacular growth over the past few years. Archeology and heritage exhibits are natural application areas for virtual environments and computer graphics, since they provide the ability to navigate 3D models of environments that no longer exist and can not be recorded on a videotape. Moreover, digital models and 3D renderings give the ability to enrich the navigation with annotations.

Our work on style has proved very interesting to architects who have a long habit of using hand-drawn schemas and wooden models to work and communicate. Wooden models can advantageously be replaced by 3D models inside a computer. Drawing, on the other hand, offers a higher level of interpretation and a richness of expression that are really needed by architects, for example to emphasize that such model is an hypothesis.

By investigating style analysis and expressive rendering, we could “sample” drawing styles used by architects and “apply” them to the rendering of 3D models. The computational power made available by computer assisted drawing can also lead to the development of new styles with a desired expressiveness, which would be harder to produce by hand. In particular, this approach offers the ability to navigate a 3D model while offering an expressive rendering style, raising fundamental questions on how to “animate” a style.

# 5. Software

## 5.1. Introduction

ARTIS insists on sharing the software that is developed for internal use. These are all listed in a dedicated section on the web site http://artis.imag.fr/Software.

## 5.2. libQGLViewer: a 3D visualization library

libQGLViewer is a library that provides tools to efficiently create new 3D viewers. Simple and common actions such as moving the camera with the mouse, saving snapshots or selecting objects are *not* available in standard APIs, and libQGLViewer fills this gap. It merges in a unified and complete framework the tools that every one used to develop individually. Creating a new 3D viewer now requires 20 lines of cut-pasted code and 5 minutes. libQGLViewer is distributed under the GPL licence since January 2003, and several hundreds of downloads are recorded each month [1].

## 5.3. PlantRad

**Participant:** Cyril Soler [contact].

PlantRad is a software program for computing solutions to the equation of light equilibrium in a complex scene including vegetation. The technology used is hierarchical radiosity with clustering and instantiation. Thanks to the latter, PlantRad is capable of treating scenes with a very high geometric complexity (up to millions of polygons) such as plants or any kind of vegetation scene where a high degree of approximate self-similarity permits a significant gain in memory requirements. Its main domains of applications are urban simulation, remote sensing simulation (See the collaboration with Noveltis, Toulouse) and plant growth simulation, as previously demonstrated during our collaboration with the LIAMA, Beijing.

[1] http://artis.imag.fr/Software/QGLViewer/

## 5.4. High Quality Renderer

**Participant:** Cyril Soler [contact].

In the context of the European project RealReflect, the ARTIS team has developed the HQR software based on the photon mapping method which is capable of solving the light balance equation and of giving a high quality solution. Through a graphical user interface, it reads X3D scenes using the X3DToolKit package developed at ARTIS, it allows the user to tune several parameters, computes photon maps, and reconstructs information to obtain a high quality solution. HQR also accepts plugins which considerably eases the developpement of new algorithms for global illumination, those benefiting from the existing algorithms for handling materials, geometry and light sources. HQR is freely available for download [2].

## 5.5. MobiNet

**Participants:** Fabrice Neyret [contact], Joëlle Thollot.

The MobiNet software allows for the creation of simple applications such as video games, virtual physics experiments or pedagogical math illustrations. It relies on an intuitive graphical interface and language which allows the user to program a set of mobile objects (possibly through a network). It is available in public domain [3] for Linux,Windows and MacOS, and originated in a collaboration with the EVASION project-team.

The main aim of MobiNet is to allow young students at high school level with no programming skills to experiment, with the notions they learn in math and physics, by modeling and simulating simple practical problems, and even simple video games. This platform has been massively used during the Grenoble INP "engineer weeks" since 2002: 150 senior high school pupils per year, doing a 3 hour practice. This work is partly funded by Grenoble INP. Various contacts are currently developed in the educational world. Besides "engineer weeks", several groups of "monitors" PhD students conducts experimentations based on MobiNet with a high scool class in the frame of the courses. Moreover, presentation in workshops and institutes are done, and a web site repository is maintained.

## 5.6. Freestyle

Freestyle is a software for Non-Photorealistic Line Drawing rendering from 3D scenes. It is designed as a programmable interface to allow maximum control over the style of the final drawing: the user "programs" how the silhouettes and other feature lines from the 3D model should be turned into stylized strokes using a set of programmable operators dedicated to style description. This programmable approach, inspired by the shading languages available in photorealistic renderers such as Pixar's RenderMan, overcomes the limitations of integrated software with access to a limited number of parameters and permits the design of an infinite variety of rich and complex styles. The system currently focuses on pure line drawing as a first step. The style description language is Python augmented with our set of operators. Freestyle was developed in the framework of a research project dedicated to the study of stylized line drawing rendering from 3D scenes. This research has lead to two publications [31], [30].

In 2008, Freestyle get a new life, completely outside ARTIS or INRIA: it was the basis of one of the 6 *Google Summer of Code* projects awarded to the *Blender Foundation* [4]! The goal of the project was to integrate Freestyle to the well known free 3D modeler *Blender*, as its standard NPR line-drawing renderer. Maxime Curioni (under the mentoring of Jean-Luc Peurière from the *Blender Foundation*), is currently making the integration. First beta versions are publicly available, and tested by enthusiasts around the web.

## 5.7. Diffusion Curves

**Participant:** Joëlle Thollot [contact].

We provide an implementation of the vector drawing tool described in the 2008 Diffusion Curves Siggraph paper. This prototype is composed of the Windows binary, along with the required shader programs (ie. in source code). The software is available for download [5] for free, for non-commercial research purposes.

[2] http://artis.imag.fr/~Cyril.Soler/HQR
[3] http://mobinet.inrialpes.fr
[4] http://www.blender.org/

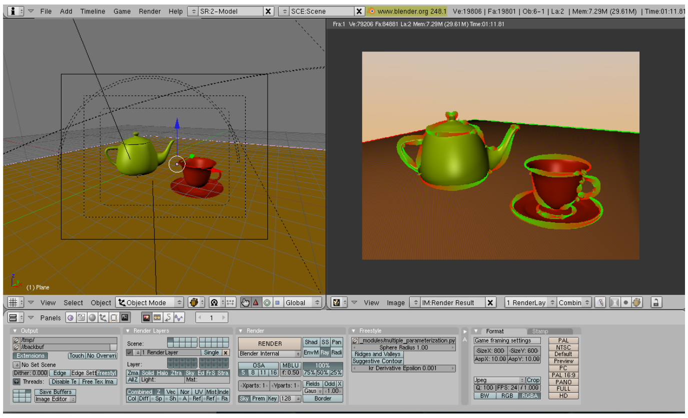

*Figure 1. As a GPL and OpenSource software, Freestyle get a new life from the blender developer community.*


*Figure 2. Diffusion curves freely downloadable demo.*

## 5.8. TiffIO: Qt 3 binding for TIFF images

**Participant:** Jean-Dominique Gascuel [contact].

TiffIO is a plug-in that add TIFF images read/write capabilities to all Qt3 and Qt4 applications using the refernce QImage class. TiffIO come with a self-test suite, and have been compiled and used successfully on a wide variety of systems, compilers and Qt version combination. A demo application enables to quickly test image loading and viewing on any platform. All TIFF operations are based on libtiff 3.8.0, this plugin is just a wrapper that enable to use it transparently from the QImage class, and the architecture defined by Qt.

TiffIO has been downloaded by a large number of developer, and integrated in a variety of commercial or internal tools, such as by *Pixar*. TiffIO is freely available for download [6].

## 5.9. VRender: vector figures

**Participant:** Cyril Soler [contact].

The VRender library is a simple tool to render the content of an OpenGL window to a vectorial device such as Postscript, XFig, and soon SVG. The main usage of such a library is to make clean vectorial drawings for publications, books, etc.

In practice, VRender replaces the z-buffer based hidden surface removal of OpenGL by sorting the geometric primitives so that they can be rendered in a back-to-front order, possibly cutting them into pieces to solve cycles.

VRender is also responsible for the vectorial snapshot feature of the QGLViewer library. VRender is released under the LGPL licence and is freely available for download [7].

## 5.10. ProLand

**Participants:** Fabrice Neyret [contact], Eric Bruneton.

Proland (for procedural landscape) is a software platform originally developed at the Evasion team-project by Eric Bruneton, and currently funded by the ANR-JCJC SimOne. The goal of this platform is the real-time quality rendering and editing of large landscapes. All features can work with planet-sized terrains, for all viewpoints from ground to space. Most of the work published by Eric Bruneton and Fabrice Neyret has been done within Proland, and a large part has been integrated in the main branch. Several licences have been transfered to companies. A free software version is about to be distributed. Eric Bruneton was hired by Google-Zürich in september 2011, but will be able to keep some participation in the project.

## 5.11. GigaVoxel

**Participants:** Fabrice Neyret [contact], Morgan Armand, Eric Bruneton, Cyril Crassin, Pascal Guehl, Eric Heitz.

Gigavoxel is a software platform initiated from the PhD work of Cyril Crassin, and currently funded by the ANR CONTINT RTIGE. The goal of this platform is the real-time rendering of very large very detailed scenes. Performances permit showing details over deep zooms and walk through very crowdy scenes (which are rigid, for the moment). The principle is GPU ray-tracing of volumetric-encoded multiscale data with minimal just-in time generation of data (accounting visibility and needed resolution) kept in a cache on GPU. The representation eases the cheap management of soft shadows, depth of field, anti-aliasing and geometric LOD. Beside the representation, data management and base rendering algorithm themself, we also worked on realtime light transport, and on quality prefiltering of complex data. This work led to numerous publications ([16], [22], [23]). Several licences have been sold to companies. A free software version is about to be distributed.

[5] http://artis.imag.fr/Publications/2008/OBWBTS08
[6] http://artis.imag.fr/Software/TiffIO
[7] http://artis.imag.fr/Software/VRender

# 6. New Results

## 6.1. Lighting and Rendering

**Participants:** Mahdi Bagher, Laurent Belcour, Georges-Pierre Bonneau, Eric Bruneton, Cyril Crassin, Jean-Dominique Gascuel, Olivier Hoel, Nicolas Holzschuch, Fabrice Neyret, Cyril Soler, Fabrice Neyret, Charles de Rousiers, Cyril Soler.

### *6.1.1. Non-linear Pre-filtering Methods for Efficient and Accurate Surface Shading*

**Participants:** Eric Bruneton, Fabrice Neyret.

Rendering a complex surface accurately and without aliasing requires the evaluation of an integral for each pixel, namely a weighted average of the outgoing radiance over the pixel footprint on the surface. The outgoing radiance is itself given by a local illumination equation as a function of the incident radiance and of the surface properties. Computing all this numerically during rendering can be extremely costly. For efficiency, especially for real-time rendering, it is necessary to use precomputations. When the fine scale surface geometry, reflectance and illumination properties are specified with maps on a coarse mesh (such as color maps, normal maps, horizon maps or shadow maps), a frequently used simple idea is to pre-filter each map linearly and separately. The averaged outgoing radiance, i.e., the average of the values given by the local illumination equation is then estimated by applying this equation to the averaged surface parameters. But this is really not accurate because this equation is non-linear, due to self-occlusions, self-shadowing, non-linear reflectance functions, etc. Some methods use more complex pre-filtering algorithms to cope with these non-linear effects. In [14] we presented a a survey of these methods. We have started with a general presentation of the problem of pre-filtering complex surfaces. We then present and classify the existing methods according to the approximations they make to tackle this difficult problem. Finally, an analysis of these methods allows us to highlight some generic tools to pre-filter maps used in non-linear functions, and to identify open issues to address the general problem.

### *6.1.2. Frequency-Based Kernel Estimation for Progressive Photon Mapping*

**Participants:** Laurent Belcour, Cyril Soler.

We have developed an extension to Hachisuka et al.'s Progressive Photon Mapping (or PPM) algorithm [32] in which we estimate the radius of the density estimation kernels using frequency analysis of light transport [29]. We predict the local radiance frequency at the surface of objects using a Gaussian approximation, and use it to drive the size of the density estimation kernels, in order to accelerate convergence (see Figure 3. The key is to add frequency information to a small proportion of photons: frequency photons. In addition to contributing to the density estimation, they will provide frequency information. This work has been published in [20].

### *6.1.3. Efficiently Visualizing Massive Tetrahedral Meshes with Topology Preservation*

**Participant:** Georges-Pierre Bonneau.

This work is the result of a collaboration with S. Hahmann from the EVASION team-project and Prof. Hans Hagen partly done during a sabbatical of G.-P. Bonneau in the University of Kaiserslautern, Germany. Interdisciplinary efforts in modeling and simulating phenomena have led to complex multi-physics models involving different physical properties and materials in the same system. Within a 3d domain, substructures of lower dimensions appear at the interface between different materials. Correspondingly, an unstructured tetrahedral mesh used for such a simulation includes 2d and 1d substructures embedded in the vertices, edges and faces of the mesh. The simplification of such tetrahedral meshes must preserve (1) the geometry and the topology of the 3d domain, (2) the simulated data and (3) the geometry and topology of the embedded substructures. This work focuses on the preservation of the topology of 1d and 2d substructures embedded in an unstructured tetrahedral mesh, during edge collapse simplification. We derive a robust algorithm, based on combinatorial topology results, in order to determine if an edge can be collapsed without changing the topology of both the mesh and all embedded substructures. Based on this algorithm we have developed a system for simplifying scientific datasets defined on irregular tetrahedral meshes with substructures, illustrated in Figure 4. We presented and demonstrated the power of our system with real world scientific datasets from electromagnetism simulations in the Springer book chapter [27].

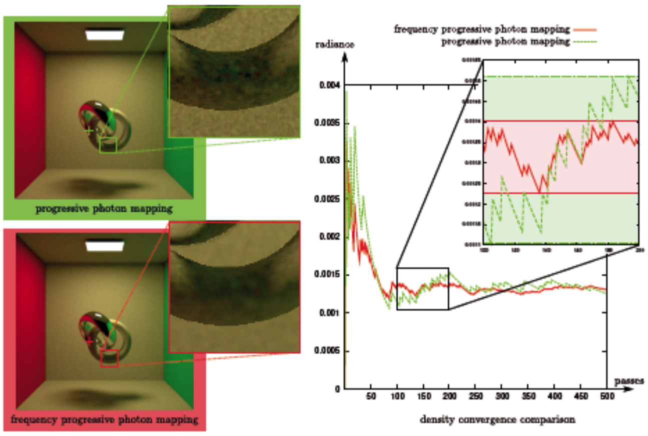


*Figure 3. In this figure we compare against progressive photon mapping with our algorithm for the convergence of an indirectly lit part of the scene. In the closeup, we show that our algorithm produces a lower varying estimate at an earlier stage of its execution.The images where produced using 100.000 photons per pass and 25% of frequency photons to make timing comparable.*

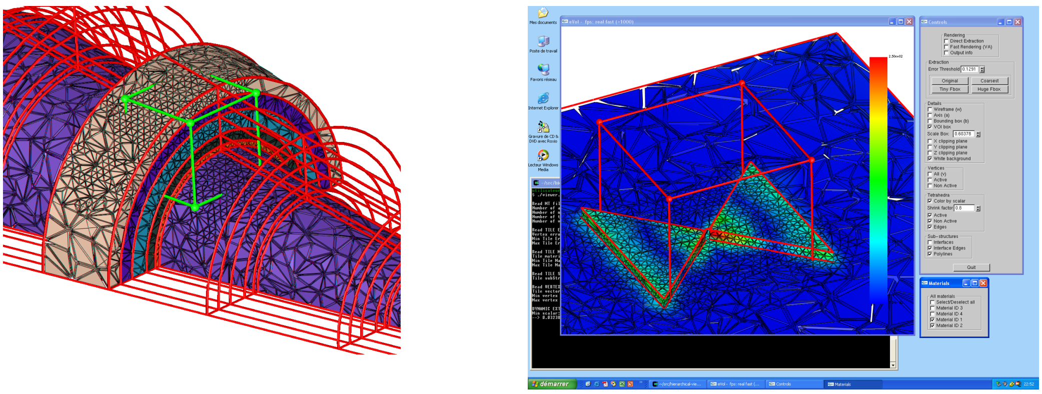

*Figure 4. Left: Variable resolution visualization of a volume mesh with multiple linear features. The topology of the substructures is guaranteed to be preserved. Right: Snapshot of the multiresolution visualization tool to explore simulation data with embedded structures on a desktop PC.*

### *6.1.4. Real-Time Rough Refraction*

**Participants:** Nicolas Holzschuch, Charles de Rousiers.

*Figure 5. Left: ground truth with total internal reflection. Right: the result with our Real-time Rough Refraction technique. While images have some differences, the result remains plausible.*

We have developed an algorithm to render objects of transparent materials with rough surfaces in real-time, under distant illumination. Rough surfaces cause wide scattering as light enters and exits objects, which significantly complicates the rendering of such materials. We present two contributions to approximate the successive scattering events at interfaces, due to rough refraction : First, an approximation of the Bidirectional Transmittance Distribution Function (BTDF), using spherical Gaussians, suitable for real-time estimation of environment lighting using pre-convolution; second, a combination of cone tracing and macro-geometry filtering to efficiently integrate the scattered rays at the exiting interface of the object. We demonstrate in I3D paper [24] the quality of our approximation by comparison against stochastic raytracing. This work is illustrated in Figure 5.

### *6.1.5. Interactive Indirect Illumination Using Voxel Cone Tracing*

**Participants:** Cyril Crassin, Fabrice Neyret.

Indirect illumination is an important element for realistic image synthesis, but its computation is expensive and highly dependent on the complexity of the scene and of the BRDF of the involved surfaces. While off-line computation and pre-baking can be acceptable for some cases, many applications (games, simulators, etc.) require real-time or interactive approaches to evaluate indirect illumination. We present in the Pacific Graphics paper [16] a novel algorithm to compute indirect lighting in real-time that avoids costly precomputation steps and is not restricted to low-frequency illumination. An illustration is given in Figure 6. It is based on a hierarchical voxel octree representation generated and updated on the fly from a regular scene mesh coupled with an approximate voxel cone tracing that allows for a fast estimation of the visibility and incoming energy. Our approach can manage two light bounces for both Lambertian and glossy materials at interactive framerates (25-70FPS). It exhibits an almost scene-independent performance and can handle complex scenes with dynamic content thanks to an interactive octree-voxelization scheme. In addition, we demonstrate that our voxel cone tracing can be used to efficiently estimate Ambient Occlusion. A primer of this work has been published as a poster (Best Poster Award [22]). Insights of the method were given in the Siggraph Talk 2011 [23].


*Figure 6. Real-time indirect illumination (25-70 fps on a GTX480): We rely on a voxel-based cone tracing to ensure efficient integration of 2-bounce illumination and support diffuse and glossy materials on complex scenes. (Right scene courtesy of G. M. Leal Llaguno)*

The publication [22] has received the *Best Poster Award* at I3D'2011.

### *6.1.6. Fast multi-resolution shading of acquired reflectance using bandwidth prediction*

**Participants:** Mahdi Bagher, Laurent Belcour, Nicolas Holzschuch, Cyril Soler.

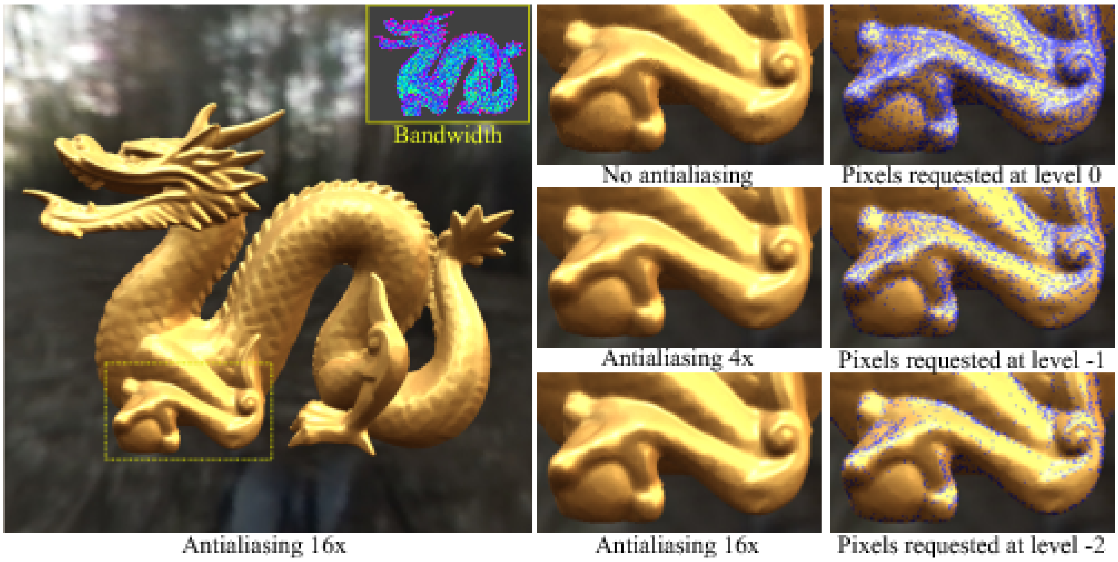


*Figure 7. The technique developped by Mahdi Bagher allows to predict in real time the local bandwidth of the image obtained by shading a measured material with all frequency distant illumination (See inset colored top-right image). This information allows a drastic economy of samples in the computation of the integrals that are needed to produce an accurate image. In particular this allows to perform multi-sampling anti-aliasing in a deferred shading pipeline with much less image-space samples than the brute-force solution.*

Shading complex materials such as acquired reflectances in multi-light environments is computationally expensive. Estimating the shading integral involves stochastic sampling of the incident illumination independently at several pixels. The number of samples required for this integration varies across the image, depending on an intricate combination of several factors. Ignoring visibility, adaptively distributing computational budget across the pixels for shading is already a challenging problem. In the paper [28] we present a systematic approach to accelerate shading, by rapidly predicting the approximate spatial and angular variation in the local light field arriving at each pixel. Our estimation of variation is in the form of local bandwidth, and accounts for combinations of a variety of factors: the reflectance at the pixel, the nature of the illumination, the local geometry and the camera position relative to the geometry and lighting. An illustration is given in Figure 7.The speed-up, using our method, is from a combination of two factors. First, rather than shade every pixel, we use this predicted variation to direct computational effort towards regions of the image with high local variation. Second, we use the predicted variance of the shading integrals, to cleverly distribute a fixed total budget of shading samples across the pixels. For example, reflection off specular objects is estimated using fewer samples than off diffuse objects.

## 6.2. Expressive Rendering and Visualization

**Participants:** Pierre Bénard, Georges-Pierre Bonneau, Alexandre Coninx, Joëlle Thollot.

### *6.2.1. Temporal Coherence for Stylized Animation*

**Participants:** Pierre Bénard, Joëlle Thollot.

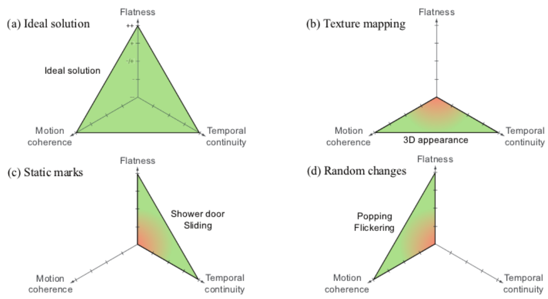


*Figure 8. In our state-of-the-art report we review and carefully compare Temporal Coherence techniques for stylized animations.*

Non-photorealistic rendering (NPR) algorithms allow the creation of images in a variety of styles, ranging from line drawing and pen-and-ink to oil painting and watercolor. These algorithms provide greater flexibility, control and automation over traditional drawing and painting. Despite significant progress over the past 15 years, the application of NPR to the generation of stylized animations remains an active area of research. The main challenge of computer generated stylized animations is to reproduce the look of traditional drawings and paintings while minimizing distracting flickering and sliding artifacts present in hand-drawn animations. These goals are inherently conflicting and any attempt to address the temporal coherence of stylized animations is a trade-off. We have published the state-of-the-art report [15] motivated by the growing number of methods proposed in recent years and the need for a comprehensive analysis of the trade-offs they propose. We formalize the problem of temporal coherence in terms of goals and compare existing methods accordingly. We propose an analysis for both line and region stylization methods and discuss initial steps toward their perceptual evaluation. The goal of our report is to help uninformed readers to choose the method that best suits their needs, as well as motivate further research to address the limitations of existing methods.

### *6.2.2. Visualization of data with uncertainty using perceptually guided procedural noise*

**Participants:** Alexandre Coninx, Georges-Pierre Bonneau.

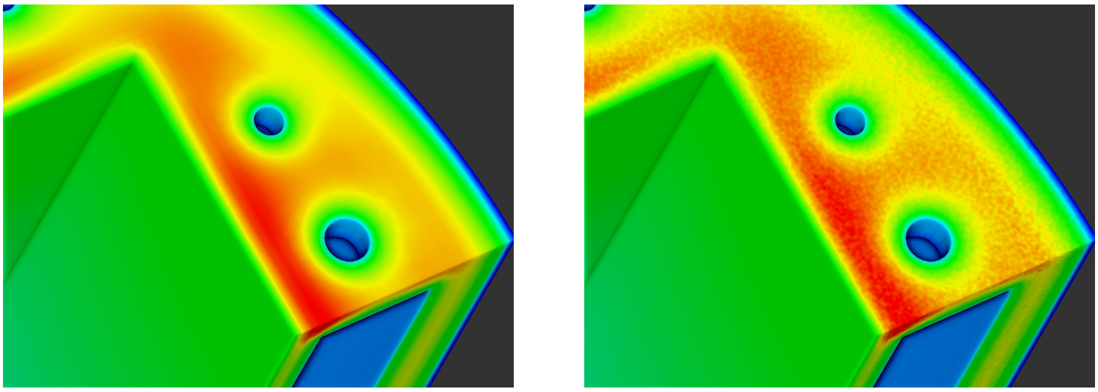

*Figure 9. Left: classical colormap visualization of scalar data without uncertainty. Right: in our technique, we pertub the input of the colormap using a perceptually guided procedural noise, scaled by the uncertainty of the data. The data and its uncertainty can be visualized in the same image.*

This work is the result of a collaboration with EdF R&D and Jacques Droulez, Director of Research at CNRS in Collège de France. In his PhD work, Alexandre Coninx has introduced a new method to visualize uncertain scalar data fields by combining color scale visualization techniques with animated, perceptually adapted Perlin noise. The parameters of the Perlin noise are controlled by the uncertainty information to produce animated patterns showing local data value and quality, as illustrated in Figure 9. In order to precisely control the perception of the noise patterns, we perform a psychophysical evaluation of contrast sensitivity thresholds for a set of Perlin noise stimuli. We validate and extend this evaluation using an existing computational model. This allows us to predict the perception of the uncertainty noise patterns for arbitrary choices of parameters. We demonstrate and discuss the efficiency and the benefits of our method with various settings, color maps and data sets. This work has been published at APGV'2011 [21].

## 6.3. Modeling and Animation

**Participants:** Georges-Pierre Bonneau, Alexandre Derouet-Jourdan, Nicolas Holzschuch, Nassim Jibai, Cyril Soler, Joëlle Thollot.

### *6.3.1. Multiscale Feature-Preserving Smoothing of Tomographic Data*

**Participants:** Nassim Jibai, Nicolas Holzschuch, Cyril Soler.

Computer tomography (CT) has wide application in medical imaging and reverse engineering. Due to the limited number of projections used in reconstructing the volume, the resulting 3D data is typically noisy. Contouring such data, for surface extraction, yields surfaces with localised artifacts of complex topology. To avoid such artifacts, we propose a method for feature-preserving smoothing of CT data, illustrated in Figure 10. The smoothing is based on anisotropic diffusion, with a diffusion tensor designed to smooth noise up to a given scale, while preserving features. We compute these diffusion kernels from the directional histograms of gradients around each voxel, using a fast GPU implementation. This work has been published as a Siggraph'2011 Poster [26].

### *6.3.2. 3D Inverse Dynamic Modeling of Strands*

**Participants:** Alexandre Derouet-Jourdan, Joëlle Thollot.

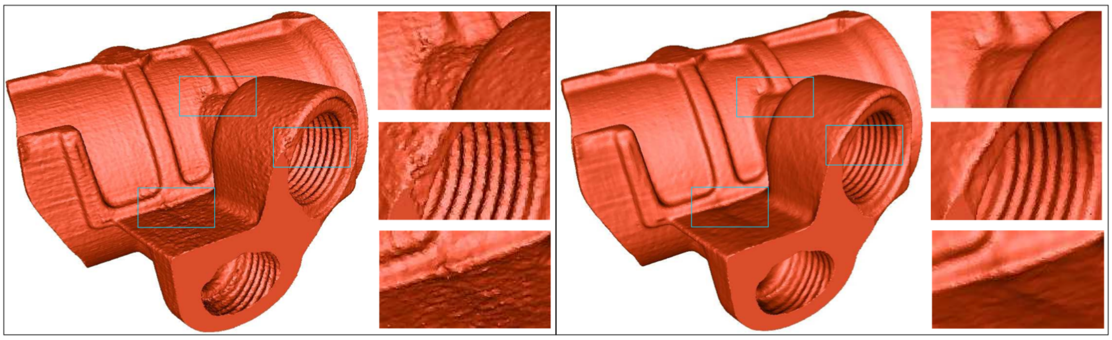

*Figure 10. Left: A contour surface extracted from noisy tomographic data contains surface noise and several topological artifacts such as small handles and holes. Right: The surface extracted from our smoothed volume is clean, and yet small features, such as the thread in the screw, and sharp edges have been preserved.*

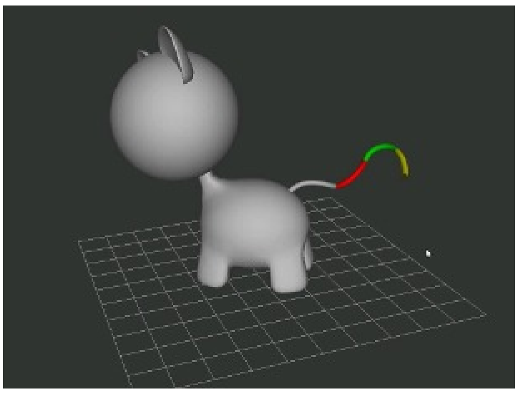

*Figure 11. Our model can physically animate the tail. The tail will retrieve its initial shape at the end of slight (possibly strong) motions.*

In this work, we propose a new method to automatically and consistently convert 3D splines into dynamic rods at rest under gravity, bridging the gap between the modeling of 3D strands (such as hair, plants) and their physics-based animation. An illustration is given in Figure 11. This work is done in collaboration with F. Bertails from the BIPOP team-project. It has been published in a Siggraph'2011 poster [25].

### 6.3.3. Lagrangian Texture Advection: Preserving both Spectrum and Velocity Field

**Participants:** Eric Bruneton, Nicolas Holzschuch, Fabrice Neyret.

Texturing an animated fluid is a useful way to augment the visual complexity of pictures without increasing the simulation time. But texturing flowing fluids is a complex issue, as it creates conflicting requirements: we want to keep the key texture properties (features, spectrum) while advecting the texture with the underlying flow — which distorts it. In this context we present a new, Lagrangian, method for advecting textures: the advected texture is computed only locally and follows the velocity field at each pixel (see Figure 12). The texture retains its local properties, including its Fourier spectrum, even though it is accurately advected. Due to its Lagrangian nature, our algorithm can perform on very large, potentially infinite scenes in real time. Our experiments show that it is well suited for a wide range of input textures, including, but not limited to, noise textures. This work has been published in the IEEE Transactions on Visualization and Computer Graphics (TVCG) [18].

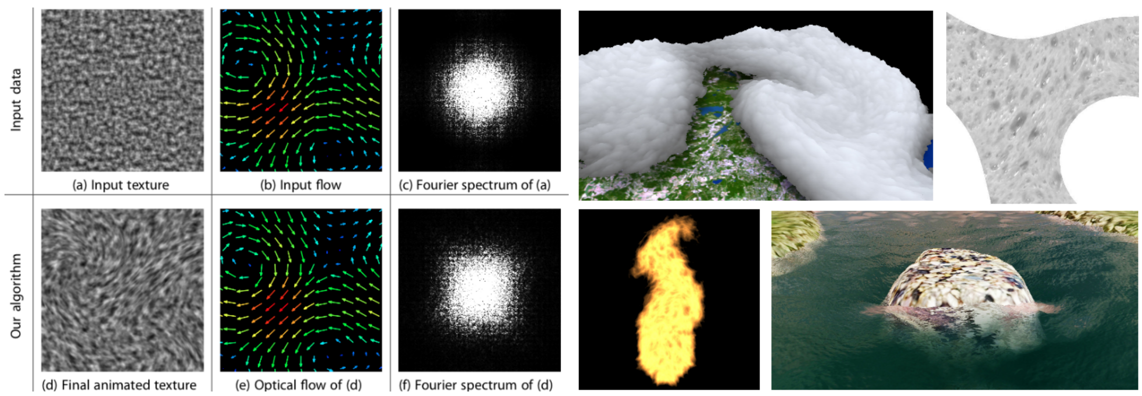


*Figure 12. Left: Our method advects open-domain textures preserving both the spectrum and the motion field, in real-time. Right: Various applications in 2D and 3D, with procedural, image, bump, displacement textures.*

### 6.3.4. Feature-Based Vector Simulation of Water Waves

**Participant:** Fabrice Neyret.

We have developed a method for simulating local water waves caused by obstacles in water streams for real-time graphics applications. Given a low-resolution water surface and velocity field, our method is able to decorate the input water surface with high resolution detail for the animated waves around obstacles. We construct and animate a vector representation of the waves. It is then converted to feature-aligned meshes for capturing the surfaces of the waves (see Figure 13). Results demonstrate that our method has the benefits of real-time performance and easy controllability. The method also fits well into a state-of-the-art river animation system. This work has been published in the Journal of Computer Animation and Virtual Worlds [19].

### 6.3.5. Volume-preserving FFD for Programmable Graphics Hardware

**Participant:** Georges-Pierre Bonneau.

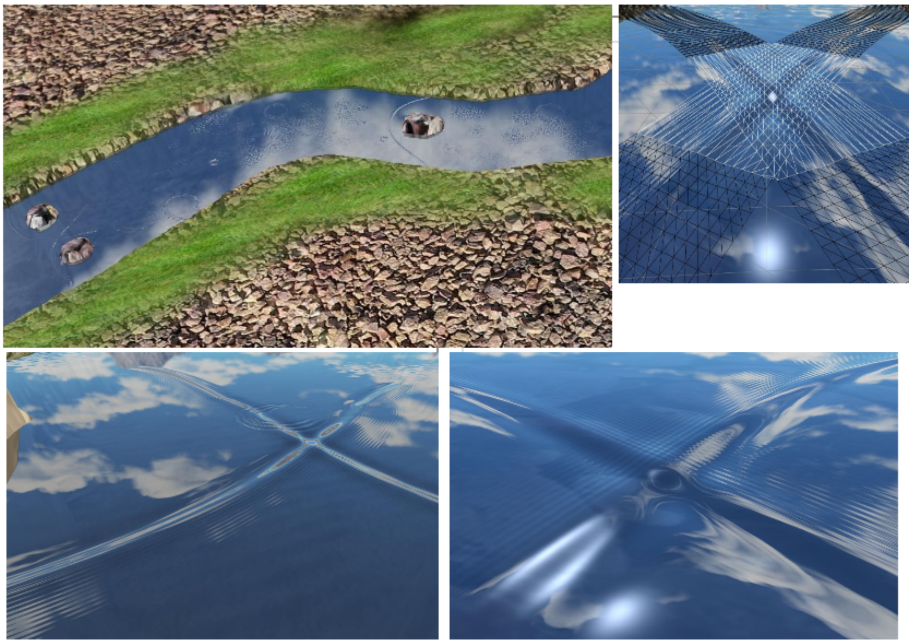

*Figure 13. Our method permits the real-time rendering of highly detailled animated features on large river scenes.*

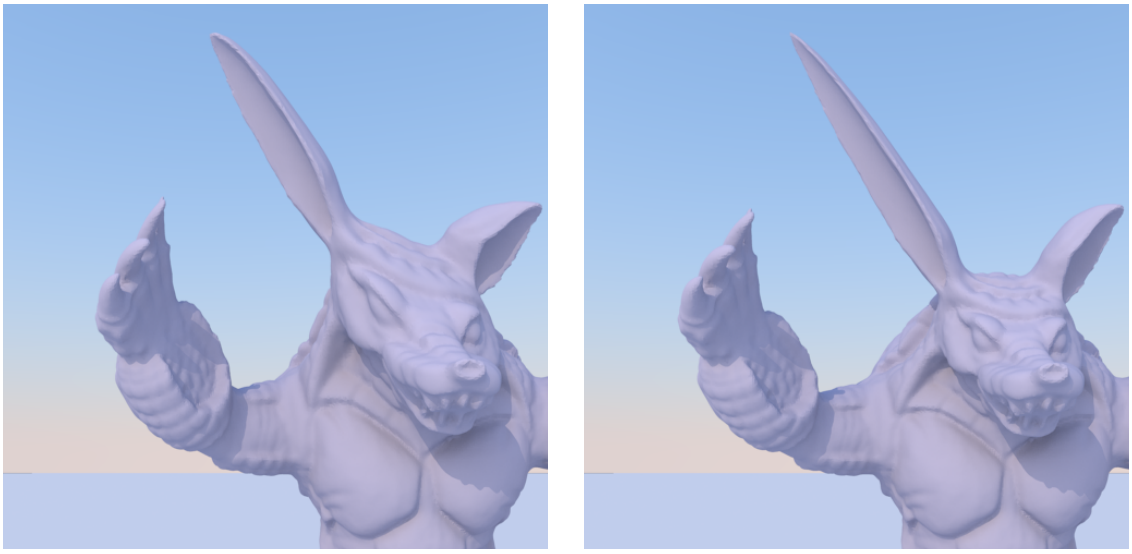

*Figure 14. Left: FFD deformation of the armadillo mesh, without volume preservation. Right: our technique: GPU-based volume preservation of the FFD deformation.*

This work is the result of a collaboration with S. Hahmann from the EVASION team-project, Prof. Gershon Elber from Technion and Prof. Hans Hagen from the University of Kaiserslautern.

Free Form Deformation (FFD) is a well established technique for deforming arbitrary object shapes in space. Although more recent deformation techniques have been introduced, amongst them skeleton-based deformation and cage based deformation, the simple and versatile nature of FFD is a strong advantage, and justifies its presence in nowadays leading commercial geometric modeling and animation software systems. Since its introduction in the late 80's, many improvements have been proposed to the FFD paradigm, including control lattices of arbitrary topology, direct shape manipulation and GPU implementation. Several authors have addressed the problem of volume preserving FFD. These previous approaches either make use of expensive non-linear optimization techniques, or resort to first order approximation suitable only for small-scale deformations. In this work we take advantage from the multi-linear nature of the volume constraint in order to derive a simple, exact and explicit solution to the problem of volume preserving FFD (see Figure 14). Two variants of the algorithm are given, without and with direct shape manipulation. Moreover, the linearity of our solution enables to implement it efficiently on GPU. The results have been published in a Visual Computer journal paper [17].

# 7. Contracts and Grants with Industry

## 7.1. GARDEN

**Participants:** Olivier Hoel, Isabelle Delore, Frank Rochet, Nicolas Holzschuch, Mahdi Mohammad-Bagher, Cyril Soler [contact].

The GARDEN project a cooperative research work with the video game company EDEN Games in Lyon. This cooperation is funded by the french “Fonds de Compétitivité des Entreprises”, the “Pole de Compétitivité” Imaginove in Lyon, the Région Rhône-Alpes, the city of Lyon and the Grand Lyon urban area. The research themes for ARTIS are real time rendering of complex materials, vegetation and human bodies for video games. This project started in March 2009, for 24 months.

# 8. Partnerships and Cooperations

## 8.1. ANR Blanc: ALTA

**Participants:** Nicolas Holzschuch [contact], Cyril Soler.

We are funded by the ANR research program "Blanc" for a joint research project with two other INRIA research teams, REVES in Sophia-Antipolis and iPARLA in Bordeaux. The goal of this project is studying light transport operators for global illumination, both in terms of frequency analysis and dimensional analysis. The grant started in October 2011, for 48 months.

## 8.2. ANR MDCO: ATROCO

**Participants:** Nicolas Holzschuch, Charles de Rousiers.

We are funded by the MDCO (Large Datasets and Knowledge) research program of the ANR, for a joint research project with the LIRIS research laboratory (Lyon) and the LSIIT research laboratory (Strasbourg), on acquisition, rendering and relighting of real objects for their inclusion in virtual scenes. This grant started in September 2007, for 36 months, and has been extended for 12 additional months.

## 8.3. ANR RIAM: CHEVEUX

**Participant:** Joëlle Thollot.

We are funded by the ANR research program RIAM (grants in multimedia projects) for a joint industrial project with two production studios: *Neomis Animation* and *BeeLight*, two other INRIA project-teams: *Bipop* and *Evasion* and a CNRS lab (Institut Jean Le Rond d'Alembert de l'Université Pierre et Marie Curie). The goal of this project is to provide rendering and animating tools of hairs for movie making. The grant started in September 2007, for 36 month.

## 8.4. ANR jeune chercheur: Animaré

**Participants:** Pierre Bénard, Pierre-Edouard Landes, Joëlle Thollot.

We are funded by the ANR research program "jeune chercheur" (grants for young research leaders) for a joint research projet with the *IPARLA* INRIA project-team in Bordeaux. The goal is to develop expressive rendering models for 2D and 3D animations. The grant started in September 2007, for 36 month.

## 8.5. ANR jeune chercheur: SimOne

**Participants:** Fabrice Neyret, Cyril Soler, Manuel Vennier.

We are funded by the ANR research program "jeune chercheur" (grants for young research leaders) for a joint research project with the *EVASION* INRIA project-team. The goal of this project is to develop "Scalable Interactive Models Of Nature on Earth" (including shape, motion and illumination models for ocean, clouds, and vegetation). The grant started in December 2010, for 36 months.

## 8.6. ANR CONTINT: RTIGE

**Participants:** Eric Bruneton, Jean-Dominique Gascuel, Nicolas Holzchuch, Fabrice Neyret.

RTIGE stands for Real-Time and Interactive Galaxy for Edutainment. This is an ANR CONTINT (Contents and Interactions) research program, for a joint research project with the *EVASION* INRIA project-team, the *GEPI* and *LERMA* research teams at Paris Observatory, and the RSA Cosmos company. We aim at integrating our results for digital planetariums. The grant started in December 2010, for 48 months.

## 8.7. ANR COSINUS: ROMMA

**Participants:** Georges-Pierre Bonneau, François Jourdes.

The ANR project ROMMA has been accepted in 2009. It started in january 2010 for a duration of 4 years. The partners of this project are academic and industry experts in mechanical engineering, numerical simulation, geometric modeling and computer graphics. The aim of the project is to efficiently and robustly model very complex mechanical assemblies. We work on the interactive computation of contacts between mechanical parts using GPU techniques. We also investigate the Visualization of data with uncertainty, applied in the context of the project.

## 8.8. LIMA

LIMA (Loisirs et Images Numériques) is a project from the Cluster ISLE (Informatique, Signal et Logiciel Embarqué). The ARTIS team is part of the LIMA project, and cooperates with other teams in the project for Numerical Images.

## 8.9. Exploradoc grant at Cornell University

**Participant:** Laurent Belcour.

The Région Rhône-Alpes has established a program to help PhD students initiating international collaboration during their PhD, with support for a six months stay in a lab in foreign university.

Laurent Belcour was funded for a six months stay at Cornell University, to work on real-time lighting and rendering algorithms.

## 8.10. International Initiatives

### 8.10.1. INRIA Associate Teams

#### 8.10.1.1. CIPRUS

Title: Challenges in Photorealistic Rendering

INRIA principal investigator: Nicolas Holzschuch

International Partner:

Institution: Cornell University (United States)

Laboratory: Program of Computer Graphics Cornell University

International Partner:

Institution: Massachusetts Institute of Technology (United States)

Laboratory: Computer graphics group CSAIL Lab

Duration: 2009 - 2011

See also: http://artis.imag.fr/Projets/Cornell-EA/ Photorealistic rendering deals with the production of pictures of virtual worlds that are as close as possible to what a real photograph of this virtual world would look like. Considerable progress has been made in recent years, and photorealistic pictures are being used in severa sectors of the industry: virtual prototyping, special effects for motion picture, video games... However, truly photorealistic pictures of a virtual world are still difficult to get. There are multiple difficulties to overcome: model acquisition, model representation, scalability, sampling and perceptual issues. Our goal in this project is to address all these issues simultaneously, targetting the production of high-quality photographic like pictures that are capable of passing a "Turing-test": they are impossible to separate from photographs of the real world, with all its complexity.

Our goal in this project is to address the many hard challenges remaining in Photorealistic Rendering, especially dealing with the inclusion of real-world objects in virtual scenes and modelling complex materials, such as low-order scattering or high-reflectance materials. The challenges we selected have two points in common: they're regarded as difficult research challenges, and they would greatly enhance the realism of the pictures generated. Both teams stand to gain from a joint work in this area. This joint work should result in several scientific breakthroughs, with the production of photorealistic pictures of highly complex virtual worlds.

### 8.10.2. Visits of International Scientists

- Professor Charles Hansen has started in November 2011 a visit of six month in the ARTIS team. His six-months visit is funded by the University of Grenoble. Charles D. Hansen received a BS in computer science from Memphis State University in 1981 and a PhD in computer science from the University of Utah in 1987. He is a professor of computer science at the University of Utah an associate director of the SCI Institute. From 1989 to 1997, he was a Technical Staff Member in the Advanced Computing Laboratory (ACL) located at Los Alamos National Laboratory, where he formed and directed the visualization efforts in the ACL. He was a Bourse de Chateaubriand PostDoc Fellow at INRIA, Rocquencourt France, in 1987 and 1988. His research interests include large-scale scientific visualization and computer graphics.
- Professor Vijay Natarajan visits the ARTIS and EVASION teams for one month in november 2011. Following a visit of G.-P. Bonneau and S. Hahmann (from EVASION), in february 2010, he collaborated with these two faculties on the topic of topology-based visualization algorithms. A common paper was already pubished by these authors at IEEE TVCG in 2010. Vijay Natarajan is an professor in the Department of Computer Science and Automation and the Supercomputer

Education and Research Centre at the Indian Institute of Science, Bangalore. He received the Ph.D. degree in computer science from Duke University in 2004 and holds the B.E. degree in computer science and M.Sc. degree in mathematics from Birla Institute of Technology and Science, Pilani, India. His research interests include scientific visualization, computational geometry, computational topology, and meshing.

# 9. Dissemination

## 9.1. Animation of the scientific community

- Nicolas Holzschuch is member of the international program committee (IPC) of the Eurographics Symposium on Rendering 2011,
- Nicolas Holzschuch is member of the "Commission d'évaluation" of INRIA,
- Joëlle Thollot is member of the IPCs of NPAR 2011 and Computational Aesthetics 2011,
- Georges-Pierre Bonneau is member of the IPC of GD/SPM 2011.

## 9.2. Teaching and PhD defense

### *9.2.1. Teaching activities*

Joëlle Thollot and Georges-Pierre Bonneau are both full Professor of Computer Science. They teach general computer science topics at basic and intermediate levels, and advanced courses in computer graphics and visualization at the master levels .

Nicolas Holzschuch teaches computer graphics at intermediate and advanced levels.

### *9.2.2. PhD of Pierre Bénard*

This PhD thesis [10] deals with non-photorealistic rendering, a sub-field of computer graphics which aims at defining creation and processing tools to stylize images and animations. It has applications in all the fields that need stylized depictions, such as entertainment (e. g., video games, animated films, cartoons), virtual her- itage, technical illustration, etc. Besides quality and expression of style, a crucial criterion to assert the quality of an image is the absence of visual artifacts. While already true for traditional art, this consideration is especially important in computer graphics. Indeed the intrin- sic discrete nature of an image can lead to artifacts. This is even more noticeable during animations, as temporal artifacts are added to spatial ones. Precisely defin- ing these artifacts is complex as certain flaws of a given style may be part of its unique and desirable quality (e. g., the imperfections in a hand-made work). The goal of this thesis is twofold: (1) To analyse and perceptually evaluate these artifacts; (2) To propose new methods for stylizing real-time 3D animations. First we present a set of techniques to ensure the coherence of line drawings ex- tracted form 3D animated scenes. Then we propose two methods to stylize shaded regions, which allow to create a wide variety of patterns. The shared ground layer of all these approaches is the use of temporally varying textures to represent the simulated media (e. g., watercolor pigments, brush strokes). Finally we describe two user studies aiming at evaluating the quality of the results produced by such techniques.

### *9.2.3. PhD of Cyril Crassin*

In this thesis [11], we present a new approach to efficiently render large scenes and detailed objects in real-time. Our approach is based on a new volumetric pre-filtered geometry representation and an asso- ciated voxel-based approximate cone tracing that allows an accurate and high performance rendering with high quality filtering of highly detailed geometry. In order to bring this voxel representation as a standard real-time rendering primitive, we propose a new GPU-based approach designed to entirely scale to the rendering of very large volumetric datasets. Our system achieves real-time rendering performance for several billion voxels. Our data structure exploits the fact that in CG scenes, details are often concentrated on the interface between free space and clusters of density and shows that volumetric models might become a valuable alternative as a rendering primitive for real-time applications. In this spirit, we allow a quality/performance trade-off and exploit temporal coherence. Our solution is based on an adaptive hierarchical data representation depending on the current view and occlusion information, coupled to an efficient ray-casting rendering algorithm. We introduce a new GPU cache mechanism providing a very efficient paging of data in video memory and implemented as a very efficient data-parallel process. This cache is coupled with a data production pipeline able to dynamically load or produce voxel data directly on the GPU. One key element of our method is to guide data production and caching in video memory directly based on data requests and usage information emitted directly during rendering. We demonstrate our approach with several applications. We also show how our pre-filtered geom- etry model and approximate cone tracing can be used to very efficiently achieve blurry effects and real-time indirect lighting.

### *9.2.4. PhD of Pierre-Edouard Landes*

Processing graphical data, either for its editing or the synthesis of new content, demands a good balance between the different sources of information one may exploit. Unlike "procedural" techniques, synthesis by example stands out thanks to its extreme ease-of-use : indeed, tasks such as identification, analysis and reproduction of the distinguishing features of the user-provided examples are left to the method itself. Such approaches, along with today's intricate editing methods have greatly favored the production of compelling graphical content at a wide scale, and henceforth facilitated the adoption of computer-assisted tools by artists. But in order to meet with success, they also have to be highly controllable without being a mere extension of the artist's hand. We explore here such concerns in the context of expressive rendering and study the interactions, may they be collaborative or competitive, between the different sources of information at the core of such processes. In our opinion, there are three main sources of information: the automatic analysis of the inputs before processing; the use of prior knowledge through predetermined models; and users' explicit intervention. Through a clever combination of these sources, we propose new expressive synthesis techniques which satisfy the aforementioned usability. More than photographic realism, expressive rendering strives for the fulfillment of less easily quantifiable goals such as the intelligibility or the aesthetic value of its results. The subjectivity behind the assessment of such criteria thus forces us to attach much importance to the careful choice of the source of information to favor; the required amount of user intervention (without being detrimental to the method's theoretical value); and the possible resort to prior models (without endangering its generality). Three main synthesis instances are studied in this document [13]: texture generation, image de-colorization, and artistic line rendering. The great disparity of inputs (raster and vector textures, complex images, 3d meshes), terms of synthesis (imitation, conversion, depiction) and objectives (preservation of a texture's visual signature, plausible restitution of chromatic contrasts, creation of drawings in accordance with users' styles) gives rise to distinct balances between those sources of information and requires the consideration of various modes of user interaction.

### *9.2.5. PhD of Charles de Rousiers*

Reproducing efficiently the appearance of complex materials is a crucial problem in the synthesis of realistic images. These are used involved in the production of video games and movies. Apart from global light transport, the realism of a synthetic image is mostly due to the adequate representation of local light transport, i.e. the interactions between light and matter. Modeling these interactions gives rise to a large variety of reflectance models. We therefore propose a classification of these models based on the scales of their ab- stract geometric details. We present in the thesis [12] the following contributions :

- a transmitting reflectance model for transparent rough surfaces such a frosted glass. The efficiency of our model allows real-time performances,
- a study and a model of energy propagation in material composed of dense packed discrete particles,
- an alternative basis for representing and lighting efficiently measured mate- rials having a low frequency reflectance.

Our contributions permit the abstraction of local interactions while keeping the realism of fully simulated local light transport models.

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