INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team artis

Acquisition, Representation and Transformations for Image Synthesis

Grenoble - Rhône-Alpes

THEME COG

Activity Report

2008

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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).

1. Team

Research Scientist
Nicolas Holzschuch [CR1, INRIA, Team Leader, HdR]
Gilles Debunne [CR2, CNRS (on leave since July 1, 2005)]
Xavier Décoret [CR2, INRIA (on leave since April 1, 2007)]
Jean-Dominique Gascuel [CR1, CNRS]
Fabrice Neyret [DR1, CNRS, HdR]
Cyril Soler [CR1, INRIA]

Faculty Member
Olivier Martin [MdC, On leave from GIPSA-lab/UJF since September, 1, 2008]
Joëlle Thollot [MdC, ENSIMAG, HdR]

External Collaborator
Frédo Durand [MIT, USA]
François Sillion [DR1, INRIA, Old Fellow, HdR]
Frank Rochet [Ingénieur Eden Games]

Technical Staff
Olivier Hoel [Ingénieur, GENAC2]

PhD Student
Elmar Eisemann [AMN (until September, 15, 2008)]
David Roger [AMN (until May, 1, 2008)]
Emmanuel Turquin [MESR (until March, 1, 2008)]
Lionel Atty [CIFRE]
Lionel Baboud [MESR]
Hedlena Bezerra [Bresilian funding "*CAPES*"]
Alexandrina Orzan [Marie Curie host VISITOR]
David Vanderhaeghe [MESR (until December, 15, 2008)]
Adrien Bousseau [MESR]
Pierre-Edouard Landes [MESR]
Thierry Stein [MESR]
Cyril Crassin [MESR]
Pierre Bénard [MESR]
Charles De Rousiers [ANR ATROCO]

Post-Doctoral Fellow
Kartic Subr [INRIA, from September, 1]
Thomas Hurtut [INRIA, from September, 1]

Administrative Assistant
Barta Angles

2. Overall Objectives

2.1. Introduction

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 and Illustration. As application domains we are working on video games, animation movies, technical illustration, virtual heritage, lighting design, rehabilitation after a traumas...

2.2. Highlights of 2008

The year 2008 was a highly productive one for the ARTIS team, with 18 publications being accepted or published in international journals and conferences. Among these achievements, we consider the following to be the highlights of the year 2008:

Publications: We had two papers accepted at the *Siggraph* conference, the reference in the field of Computer Graphics: a joint work with *Adobe Research* on diffusion curves, a new drawing tool for smooth-shaded images (see section 6.3.6), and a joint work with MIT, UCSD, PDI/Dreamworks and NVidia Research on meshless hierarchical representations for interactive simulation of global illumination [17]. These two papers are also published in the international journal *ACM Transactions on Graphics*.

Habilitation: Joëlle Thollot has completed and defended her "Habilitation à Diriger des Recherches" (see 9.1.4) in November 2008.

Cooperation with *Adobe*: we have an ongoing cooperation with the *Adobe* company; this cooperation has been materialized by several internships by students of the ARTIS team, several joint publications, including at the Siggraph conference. For the year 2008, this cooperation also materialized with financial support from the *Adobe* company. Three grants, for a total of $45,000 were awarded to the ARTIS team.

Team: the team was expanded by the addition of one new faculty member, Olivier Martin, currently on leave from Université Joseph Fourier. Nicolas Holzschuch returned from a sabbatical stay at Cornell University in September 2008. We have also recruited two new post-doctoral students in 2008, Kartic Subr (UC Irvine) and Thomas Hurtut (Télécom Paris/Polytechnique Montréal).

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

Keywords: *Global illumination*, *inverse rendering*, *multi-resolution*.

Participants: Lionel Atty, Cyril Crassin, Elmar Eisemann, Nicolas Holzschuch, David Roger, Charles de Rousiers, François Sillion, Cyril Soler, Kartic Subr, Emmanuel Turquin.

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 mainly focused on light transfer simulation in scenes containing vegetation, for which we develop efficient instantiation-based hierarchical simulation algorithms.

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, Hedlena Bezerra, Adrien Bousseau, Elmar Eisemann, Pierre-Edouard Landes, Thomas Hurtut, Alexandrina Orzan, Thierry Stein, François Sillion, Cyril Soler, Joëlle Thollot, David Vanderhaeghe.

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. Guiding principles

We base our research on the following principles:

3.4.1. 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.

3.4.2. 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.

3.4.3. 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.

3.4.4. 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 [48]).

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

Participant: Gilles Debunne [contact].

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

Participants: Cyril Soler [contact], François Sillion.

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.

5.4. High Quality Renderer

Participants: Cyril Soler [contact], François Sillion.

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 is not yet available for download.

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 [2] 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.

This year, we obtained an LJK founding for 6 months of engineer which allowed us (with collaboration of the SED service) to port MobiNet to various OS with a decent packaging, and to delivered the new version 1.1.100. Moreover, we presented the software and our pedagogical experiments at APMEP08 [38], the French national conference of maths teachers, and published various follow-up article [25], [26], [27]

5.6. Basilic : an Automated Bibliography Server

Participant: Gilles Debunne [contact].

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

Basilic is a tool that automates the diffusion of research results on the web. It automatically generates the publication part of a project web site, creating index pages and web pages associated to each publication. These pages provide access to the publication itself, its abstract, associated images and movies, and anything else via web links [3].

All bibtex related information is stored in a database that is queried on the fly to generate the pages. Everyone can very easily and quickly update the site, thus guaranteeing an up-to-date web site. BibTeX and XML exports are available, and are for instance used to generate the bibliography of this activity report. Basilic is released under the GPL licence and is freely available for download [4].

5.7. XdkBibTeX : parsing bibtex files made easy

Participant: Xavier Décoret [contact].

This program provides parsers and utility functions for the BibTeX file format. The core of the library is a C++ compiled as a library. Based on this library, bindings for different languages are provided using SWIG.

The long term goal is to replace the bibtex program and its associated BST language for style files by a more recent and powerful scripting language (such a Python, Ruby, Php, Perl...) or by Java. The other goal is to allow easy writing of BibTeX related tools such as converters to other format. XdkBibTeX is used by Basilic to import from bibtex files. XdkBibTeX is released under the GPL licence and is freely available for download [5]

5.8. 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 [47], [45].

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* [6]! 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 [7] (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.

5.9. Diffusion Curves

Participants: Adrien Bousseau, Alexandrina Orzan, Joëlle Thollot [contact].

We provide an implementation of the vector drawing tool described in the Diffusion Curves Siggraph paper (see section 6.3.6). This prototype is composed of the Windows binary, along with the required shader programs (ie. in source code). The software is available for download [8] for free, for non-commercial research purposes.

[3] See for instance http://artis.inrialpes.fr/Publications
[4] http://artis.imag.fr/Software/Basilic
[5] http://artis.imag.fr/Membres/Xavier.Decoret/resources/xdkbibtex/
[6] http://www.blender.org/
[7] http://maximecurioni.com/freestyle/?page_id=2
[8] http://artis.imag.fr/Publications/2008/OBWBTS08

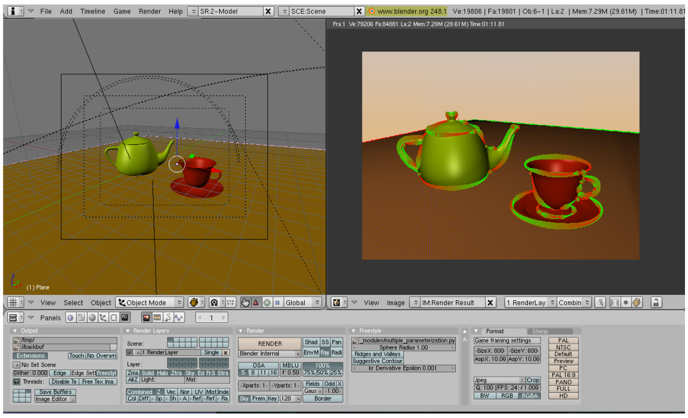


Figure 1. As a GPL and OpenSource software, Freestyle get a new life from the blender developer community.

Figure 2. Diffusion curves freely downloadable demo.

5.10. 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 [9].

5.11. 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 [10].

5.12. SciPress

Participant: Xavier Décoret [contact].

SciPres is a system for creating animated presentations. It was inspired by Slithy, a python-based system developped by Douglas Zonker. In short, SciPres is to PowerPoint what LaTeX is to Microsoft Word: you script your presentation using a text editor, rather than using a WYSIWYG system. SciPres is released under the GPL licence and is freely available for download [11].

6. New Results

6.1. Lighting and Rendering

Participants: Elmar Eisemann, Nicolas Holzschuch, David Roger, Charles de Rousiers, François Sillion, Cyril Soler, Kartic Subr, Emmanuel Turquin.

6.1.1. Meshless Finite Element Methods for Hierarchical Global Illumination

Participants: François Sillion, Emmanuel Turquin.

We have developed a meshless finite element framework for solving light transport problems. Traditionally, finite element methods use basis functions, relying on a parametrization of the mesh surface. Our experience show that the creation of a suitable parametrization is difficult, error-prone and sensitive to the quality of the input geometry. Clustering methods have been developed to overcome these difficulties, but they, too, are error-prone and sensitive to the quality of input geometry.

[9] http://artis.imag.fr/Software/TiffIO
[10] http://artis.imag.fr/Software/VRender
[11] https://artis.imag.fr/Membres/Xavier.Decoret/resources/scipres/wiki

Figure 3. Our interactive global illumination algorithm, on a scene with complex geometry. This scene runs at 7.2 fps.

The resulting light transport solutions tend to exhibit discontinuities, necessitating heuristic post-processing before visualization. Due to these problems finite element methods are rarely used in production. The core idea of our approach is to use finite element basis functions induced by hierarchical scattered data approximation techniques. This leads to a mathematically rigorous recipe for meshless finite element illumination computations. As a main advantage, our approach decouples the function spaces used for solving the transport equations from the representation of the scene geometry. The resulting solutions are accurate, exhibit no spurious discontinuities, and can be visualized directly without post-processing, while parametrization, meshing and clustering problems are avoided. The resulting methods are furthermore easy to implement.

We have demonstrated the power of our framework by describing implementations of hierarchical radiosity, glossy precomputed radiance transfer from distant illumination, and diffuse indirect precomputed transport from local light sources (see Figure 3). Moreover, we have described how to directly visualize the solutions on graphics hardware.

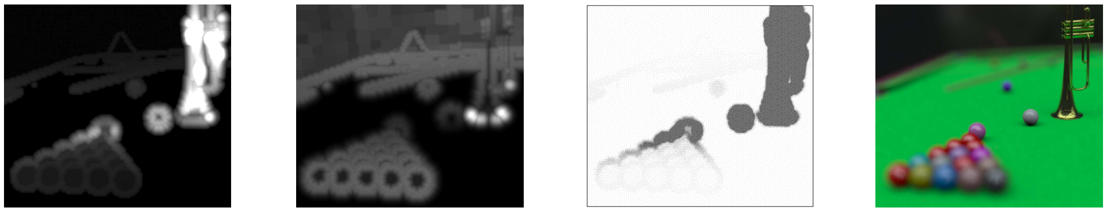
This research, done in cooperation with Jaakko Lehtinen and Janna Kontkanen of the Helsinki University of Technology and Mathias Zwicker of the University of California San Diego has been rewarded by a *SIGGRAPH 2008* presentation, published in the *ACM Transaction on Graphics* journal [17].

6.1.2. Fourier Depth of Field

Participants: Nicolas Holzschuch, François Sillion, Cyril Soler, Kartic Subr.

The simplistic pinhole camera model used to teach perspective (and computer graphics) produces sharp images because every image element corresponds to a single ray in the scene. Real-life optical systems such as photographic lenses, however, must collect enought light to accomodate the sensitivity of the imaging system, and therefore combine light rays coming through a finite-sized aperture. Focusing mechanisms are needed to choose the distance of an “in-focus" plane, which will be sharply reproduced on the sensor, while objects appear increasingly blurry as their distance to this plane increases. The visual effect of focusing can be dramatic and is used extensively in photography and film, for instance to separate a subject from the background.

Although the simulation of depth of field in Computer Graphics has been possible for more than two decades, this effect is still rarely used in practice because of its high cost: the lens aperture must be densely sampled to produce a high-quality image. This is particularly frustrating because the defocus produced by the lens is not increasing the visual complexity, but rather removing detail! In this paper, we propose to exploit the blurriness



(a) Image sampling density (b) Lens sampling density (c) Image space samples (d) Reconstructed image

Figure 4. (a) The image sampling density predicts that the shiny regions of the trumpet, with high curvature and in focus need to be sampled most profusely in the image. (b) The aperture density predicts that defocused regions need to be sampled densely while the ball in focus requires very few samples over the aperture. (c) the image samples obtained from the image sampling density. (d) The image is reconstructed from scattered radiance estimates.

of out-of-focus regions to reduce the computation load. We study defocus from a signal processing perspective and propose a new algorithm that estimates local image bandwidth. This allows us to reduce computation costs in two ways, by adapting the sampling rate over both the image and lens aperture domain.

In image space, we exploit the blurriness of out-of-focus regions by downsampling them: we compute the final image color for only a subset of the pixels and interpolate. Our motivation for adaptive sampling over the lens comes from the observation that in-focus regions do not require a large number of lens samples because they do not get blurred, in contrast to out of focus regions where the large variations of radiance through the lens requires many samples. More formally, we derive a formula for the variance over the lens and use it to adapt sampling for a Monte-Carlo integrator. Both image and lens sampling are derived from a Fourier analysis of depth of field that extends recent work on light transport [43]. In particular, we show how image and lens sampling correspond to the spatial and angular bandwidth of the lightfield.

We emphasize that sparsely sampled images resulting from simulation of depth of field cannot be splatted upto material or depth discontinuities (as is done for pinhole camera simulation), due to the integral over the aperture. Blurred discontinuities in the image need to be sampled adequately, which requires a systematic treatment of occlusion and aperture effects.

Figure 4 shown an example of applying our technique to a scene with high depth of field variations. As predicted, the spatial sampling density is high in the regions with high specularity or depth discontinuities, and the angular sampling density is high where un-focused pixels are the result of averaging high variance regions of the incoming illumination. Spatial samples therefore stick to regions with high spatial frequencies.

This paper was accepted for a journal publication in *ACM Transactions on Graphics*[22].

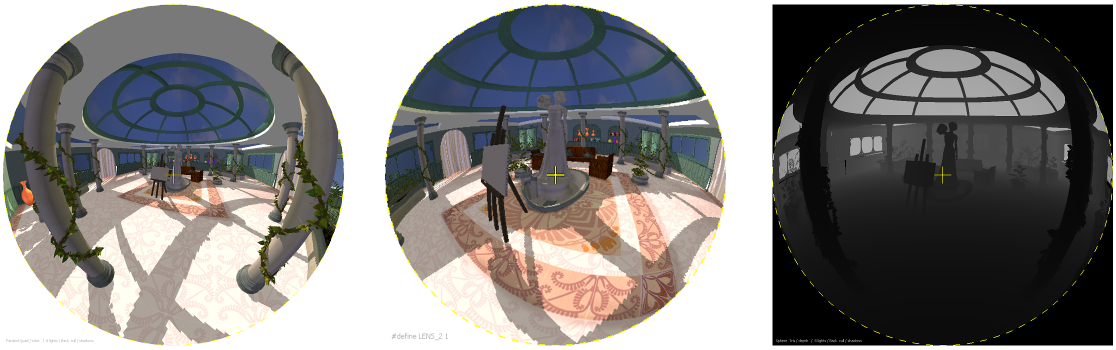
6.2. GPU Rendering

Participants: Cyril Crassin, Xavier Décoret, Elmar Eisemann, Jean-Dominique Gascuel, Nicolas Holzschuch, Fabrice Neyret.

6.2.1. Non-Linear Projections on the GPU

Participants: Jean-Dominique Gascuel, Nicolas Holzschuch.

Linear perspective projections are used extensively in graphics. They provide a non-distorted view, with simple computations that map easily to hardware. Non-linear projections, such as the view given by a fish-eye lens are also used, either for artistic reasons or in order to provide a larger field of view, *e.g.* to approximate environment reflections or omnidirectional shadow maps. As the computations related to non-linear projections are more involved, they are harder to implement, especially in hardware, and have found little use so far in practical



(a) Paraboloid projection. (b) Fish-Eye Lense. (c) Shadow Map using Cos-Sphere.

Figure 5. Non-Linear projections on the GPU.

applications. We have applied existing methods for non-linear projections to a specific class: non-linear projections with a single center of projection, radial symmetry and convexity. This class includes, but is not limited to, paraboloid projections, hemi-spherical projections and fish-eye lenses.

We have shown that, for this class, the projection of a 3D triangle is a single curved triangle, and we have given a mathematical analysis of the curved edges of the triangle; this analysis allows us to reduce the computations involved, and to provide a faster implementation. The overhead for non-linearity is bearable and can be balanced with the fact that a single non-linear projection can replaces as many as five linear projections (in a hemicube), with less discontinuities and a smaller memory cost, thus making non-linear projections a practical alternative (see Figure 5).

This work has been accepted for publication at the *ACM Symposium on Interactive 3D Graphics and Games 2008* [33].

6.2.2. *Plausible Image Based Soft Shadows Using Occlusion Textures*

Participants: Xavier Décoret, Elmar Eisemann.

Computing soft shadows in real-time is a challenging problem. Computations are inherently complex. However, the human brain is relatively bad at "analysing" soft shadows, and approximate shadows are easily accepted as realistic. Based on that observation, we can tradeoff some accuracy for some computation speed.

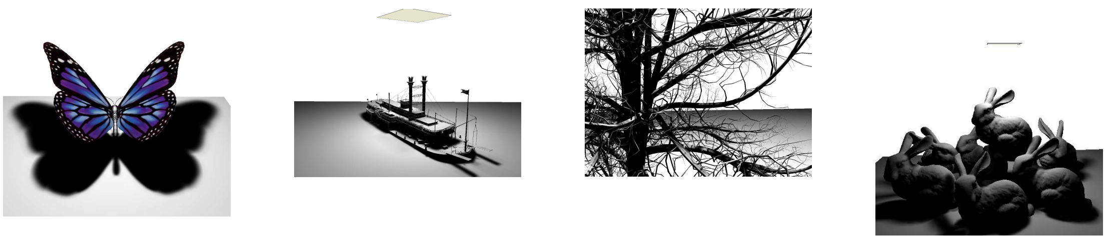


Figure 6. Plausible soft shadows, computed in realtime on GPU by our algorithm.

We proposed a method for computing "plausible" soft shadows on the GPU. The geometry of the scene is approximated by a set of planar bitmasks (slices), using the fast scene voxelisation introduced in previous section. We then use the NBuffer recently introduced by Xavier Décoret to pre-compute convolution of this bitmasks by different kernel size. As shown by Cyril Soler in an older work, at a given point, the soft shadows caused by one slice is given by the convolution of the slice with a kernel whose size and location depends of the point and the light source. Combining our GPU based encoding of slices and convolutions, we are able to compute this result very efficiently in a fragment shader. The problem that remains is the combination of the shadows caused by each slice. We introduce a novel scheme, based on probabilities, that perform significantly better than previous methods, although it is not exact. As a result, we can compute very appealing soft shadows (see Figure 6) on arbitrary scenes (complex geometry, high polygon count, animated scenes) very fast, with all computations taking place on GPU.

The results have been accepted for publication in *Computer Graphics Forum* [15].

6.2.3. Sample Based Visibility for Soft Shadows using Alias-free Shadow Maps

Participant: Elmar Eisemann.

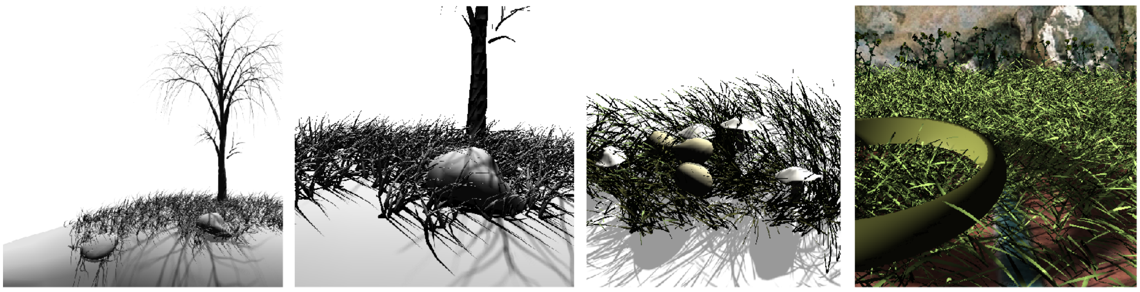


Figure 7. Left to right: 90k triangles (7 fps), zoomed (4.5 fps), 70k triangles (4.8 fps), ring scene: 379k triangles (0.65 fps).

We introduced an accurate real-time soft shadow algorithm that uses sample based visibility. Initially, we presented a GPU-based alias-free hard shadow map algorithm that typically requires only a single render pass from the light, in contrast to using depth peeling and one pass per layer. For closed objects, we also suppress the need for a bias. The method is extended to soft shadow sampling for an arbitrarily shaped area-/volumetric light source using 128-1024 light samples per screen pixel. The alias-free shadow map guarantees that the visibility is accurately sampled per screen-space pixel, even for arbitrarily shaped (e.g. non-planar) surfaces or solid objects. Another contribution is a smooth coherent shading model to avoid common light leakage near shadow borders due to normal interpolation.

This work was done in collaboration with Erik Sintorn and Pr. Ulf Assarson, and was published at *Eurographics Symposium on Rendering 2008* [20]. The work was selected as one of NVidia's technical showcases for *SIGGRAPH 2008* and David Luebke (NVIDIA) provided a detailed presentation of our technique in form of a SIGGRAPH course.

6.2.4. Real-time rendering of large detailed volumes

Participants: Cyril Crassin, Elmar Eisemann, Fabrice Neyret.

Cyril Crassin started his PhD thesis with Fabrice Neyret, in collaboration with Sylvain Lefebvre (*Reves* project-team), on the the real-time rendering of very large and detailed volumes, taking advantage of GPU-adapted data-structure and algorithms. The main target corresponds to the cases where detail is concentrated at the interface between free space and clusters of density found in many natural volume data such as cloudy sky or vegetation, or data represented as generalized parallax maps, hypertextures or volumetric textures.

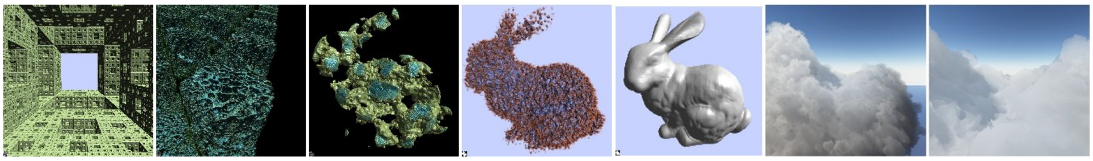


Figure 8. Various complex large and detailled scenes which our method allows for the interactive exploration despited their voxelisation far exceed the GPU memory.

The new method is based on a dynamic N3 tree storing MIP-mapped 3D texture bricks in its leaves. We load on the fly on GPU only the necessary bricks at the necessary resolution, taking into account visibility. This maintains low memory consumption during interactive exploration and minimizes data transfer. Our ray marching algorithm benefits from the multiresolution aspect of our data structure and provides real-time performance.

A paper has been accepted at the *ACM Symposium on Interactive 3D Graphics and Games 2009* [31].

6.2.5. Scalable Real-Time Animation of Rivers

Participants: Fabrice Neyret, Nicolas Holzschuch.

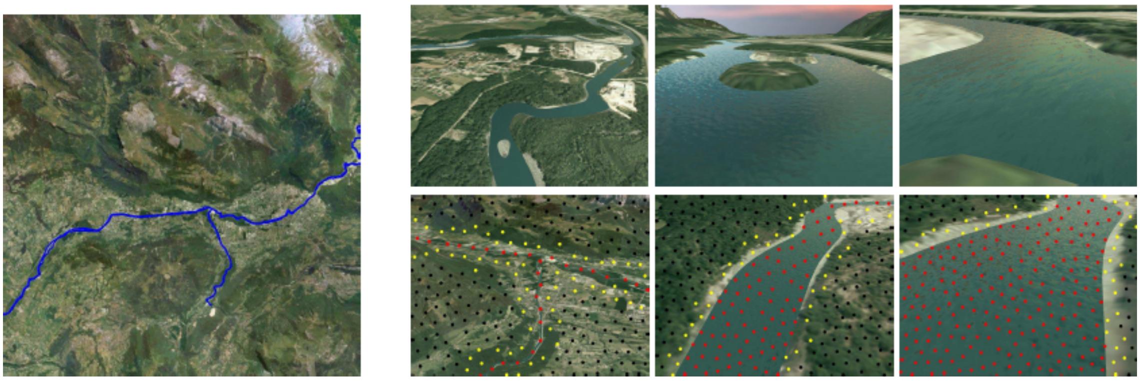


Figure 9. Our river animation and reconstruction model handles the real-time dynamic exploration from landscape-scale to close-scale. Advected particles obey a Poisson-disk distribution in screen space.

Many recent games and applications target the interactive exploration of realistic large scale worlds. These worlds consist mostly of static terrain models, as the simulation of animated fluids in these virtual worlds is computation- ally expensive. Adding flowing fluids, such as rivers, to these virtual worlds would greatly enhance their realism, but causes specific issues: as the user is usually observing the world at close range, small scale details such as waves and ripples are important.

However, the large scale of the world makes classical methods impractical for simulating these effects. We found an algorithm for the interactive simulation of realistic flowing fluids in large virtual worlds. Our method relies on two key contributions: the local computation of the velocity field of a steady flow given boundary conditions, and the advection of small scale details on a fluid, following the velocity field, and uniformly sampled in screen space.

This work, done in collaboration with the *Evasion* project-team in the scope of the PhD thesis of Qizhi Yu (supervised by Fabrice Neyret and Eric Bruneton), was accepted in the *Eurographics 2009* conference, and published in the *Computer Graphics Forum* journal [24].

6.2.6. Wind projection basis for real-time animation of trees

Participant: Lionel Baboud.

Figure 10. Various deformation modes of a walnut tree model

With this work we proposed a real-time method to animate complex scenes of thousands of trees under a user-controllable wind load. Firstly, modal analysis is applied to extract the main modes of deformation from the mechanical model of a 3D tree. The novelty of our contribution is to precompute a new basis of the modal stress of the tree under wind load. At runtime, this basis allows to replace the modal projection of the external forces by a direct mapping for any directional wind. We showed that this approach can be efficiently implemented on graphics hardware. This modal animation can be simulated at low computation cost even for large scenes containing thousands of trees.

This work, done in collaboration with the *Evasion* project-team and the *LadHyX*[12] was accepted in the *Eurographics 2009* conference, and published in the *Computer Graphics Forum* journal [14].

6.2.7. Interactive multiple anisotropic scattering in clouds

Participants: Cyril Crassin, Fabrice Neyret.

This work was done in collaboration with the *Evasion* project-team, in the scope of the PhD thesis of Antoine Bouthors (supervised by Fabrice Neyret).

We proposed an algorithm for the real time realistic simulation of multiple anisotropic scattering of light in a volume. Contrary to previous real-time methods we account for all kinds of light paths through the medium and preserve their anisotropic behavior. Our approach consists of estimating the energy transport from the illuminated cloud surface to the rendered cloud pixel for each separate order of multiple scattering. We represented the distribution of light paths reaching a given viewed cloud pixel with the mean and standard deviation of their entry points on the lit surface, which we call the collector area. At rendering time for each pixel we determine the collector area on the lit cloud surface for different sets of scattering orders, then we infer the associated light transport. The fast computation of the collector area and light transport is possible thanks to a preliminary analysis of multiple scattering in plane-parallel slabs and does not require slicing or marching through the volume.

Rendering is done efficiently in a shader on the GPU, relying on a cloud surface mesh augmented with a Hypertexture to enrich the shape and silhouette. We demonstrated our model with the interactive rendering of detailed animated cumulus and cloudy sky at 2-10 frames per second.

This work was accepted for publication in the *ACM Symposium on Interactive 3D Graphics and Games 2008* [29].

[12] joint laboratory of Ecole Polytechnique and CNRS

Figure 11. Real-time high quality rendering of detailled animatable clouds, taking into account anisotropic multiple Mie scattering.

6.2.8. Single-pass GPU Solid Voxelization and Applications

Participants: Xavier Décoret, Elmar Eisemann.

We designed a single-pass technique to voxelize the interior of watertight 3D models with high resolution grids in realtime during a single rendering pass. Further, we developed a filtering algorithm to build a density estimate that allows the deduction of normals from the voxelized model. This is achieved via a dense packing of information using bitwise arithmetic. We demonstrated the versatility of the method by presenting several applications like translucency effects, CSG operations, interaction for particle simulations, and morphological operations. The speed of our method opens up the road for previously impossible approaches in realtime: 300,000 polygons are voxelized into a grid of one billion voxels at > 90Hz with a recent graphics card.

This work was published at *Graphics Interface 2008* conference [32].

6.3. Expressive Rendering

Participants: Pierre Bénard, Hedlena Bezerra, Adrien Bousseau, Elmar Eisemann, Pierre-Edouard Landes, Alexandrina Orzan, Thierry Stein, François Sillion, Cyril Soler, Joëlle Thollot, David Vanderhaeghe.

6.3.1. Clip Art Rendering of Smooth Isosurfaces

Participant: Elmar Eisemann.

Clip art is a simplified illustration form consisting of layered filled polygons or closed curves used to convey 3-D shape information in a 2-D vector graphics format. This paper focuses on the problem of direct conversion of smooth surfaces, ranging from the free-form shapes of art and design to the mathematical structures of geometry and topology, into a clip art form suitable for illustration use in books, papers and presentations. We show how to represent silhouette, shadow, gleam and other surface feature curves as the intersection of implicit surfaces, and derive equations for their efficient interrogation via particle chains. We further describe how to sort, orient, identify and fill the closed regions that overlay to form clip art. We demonstrate the results with numerous renderings used to illustrate the paper itself (see Figure 12).

This work was started during the ExploraDoc stay of Elmar Eisemann at University of Illinois, Urbana-Champaign, and has been accepted for publication in IEEE Transactions on Visualization and Computer Graphics [23].

Figure 12. Application of our algorithm for clip art rendering of smooth isosurfaces.

6.3.2. Dynamic Grouping

Participants: Hedlena Bezerra, Elmar Eisemann, Xavier Décoret, Joëlle Thollot.

One fundamental question in expressive rendering is: how to emphasize certain objects of the depicted scene? Answering this question allows the creation of efficient visual representations of a scene that communicate a specific message or are easier to understand. Artists have done this for centuries. Thus numerous stylization techniques abstract or simplify the visual representation of the scene according to what we call a level of abstraction (LOA). Such an LOA is determined for each object before applying the stylization technique. The choice of LOA depends on the artist's goal and often the viewpoint. Our motivation is to address this problem with a system that accounts for dynamically varying scenes while allowing intuitive controls.

We propose a real-time technique to cluster a dynamic 3D scene. The user can devise clustering strategies taking into account any attribute of the scene. Once the clustering is done, a temporally coherent LOA is assigned to each group and used to drive the stylization. We show how to achieve an automatic, yet controllable output that can then be used with any rendering style. This stylization can be a function of the criteria used to cluster, but also of other object information available from the cluster's members.

This system have been published at the *6th International Symposium on Non-photorealistic Animation and Rendering* [28].

6.3.3. Label Placement

Participants: Xavier Décoret, Thierry Stein.

Expressing information through 3D visualization has become popular for a wide gamut of applications ranging from entertainment to serious applications A key aspect in this communication with 3D representations is labeling, or visibly attaching text that provides more information about certain regions. Labeling has been a standard tool that enables attaching information and also drawing attention to certain regions. (e.g. life points of other players in WoW, name of avatars in Second Life, description of shops in Google Maps and indicating organ dimensions in medical applications).

While labeling has been extensively used in 2D illustration, it is indeed challenging to extend and automate the labeling process for images of 3D representations. The key point here is that the viewpoint is "inside" the scene. A consequence of being immersed is that label placement poses more challenges than when labels have to be layed out "around" an annotated object, as typically the case in most existing work. Rather than to produce aesthetic (i.e close to what talented illustrators can do) layouts for particulars view, our goal is to guarantee that all annotations relevant for the current viewpoint are adequately presented to the user, while

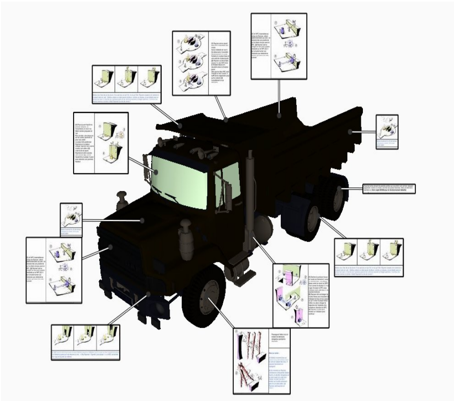


Figure 13. An example of dynamic labeling for a complex object.

attempting to minimize interference with the 3D experience of scene navigation. In particular, we pay attention to enforce temporal coherence.

This work have been published at the *6th International Symposium on Non-photorealistic Animation and Rendering* [34].

6.3.4. Dynamic Storyboard

Participants: Nicolas Holzschuch, Thierry Stein.

Representing a complex set of movements in a condensed way, especially in an image, is a problem coming up in many areas, from scientific visualization to storyboards' or comics' conception. An image (seen as a 2D space) can't represent particles' movement in 4D space without loosing a piece of information. To balance this loss, many techniques were implemented, from adding visual clues in an image to splitting movement in a sequence made of several images.

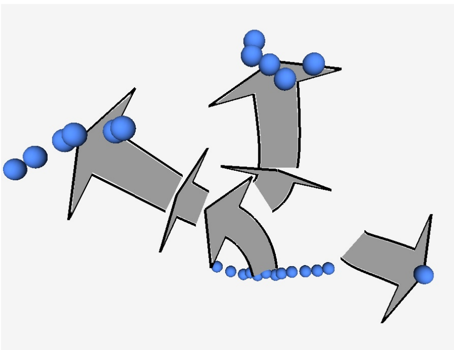


Figure 14. An example of storyboard created from an animation of particles.

We presented [39] a pipeline to generate, from data corresponding to a set of movements in 4D space for a given temporal period, a storyboard summarizing in a comprehensible and efficient way the animation as a whole. Our method consists in grouping data with similar paths , then in segmenting the resulting groups so as to isolate key positions. At last, we performed a stylized rendering of the trajectory corresponding to each segment. The main purpose of our work was to allow a dynamical exploration of the final storyboard, so that a user could observe data at different scales, spacial as well as temporal.

6.3.5. Color Perception - Greyscale conversion

Participants: Pierre-Edouard Landes, Joëlle Thollot.

(a) (b) (c)

Figure 15. If we directly assign luminance to every color of the input (a), original chromatic information is lost and the resulting image does not account for any color-related perceptual effects: the flower appears dull in such a simplistic approach (b). By using an appropriate lightness model and local contrast enhancement, we can obtain a more perceptually-accurate result (c).

The basic problem of greyscale transformation is to reproduce the intent of the colour original, its contrasts and salient features, while preserving the perceived magnitude and direction of its gradients. The transformation consists of two interdependent tasks: a mapping that assigns a grey value to each pixel or colour, and a discriminability constraint so that the achromatic differences match their corresponding original colour differences.

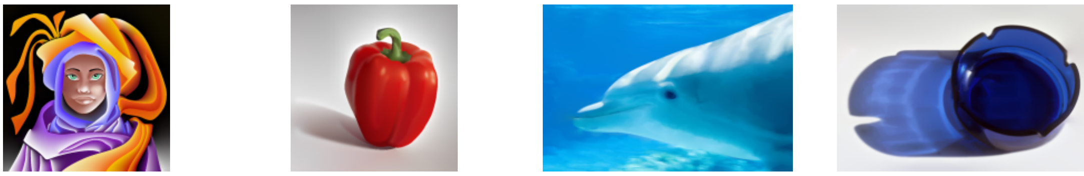
The goal of this work is to create a perceptually accurate version of the colour image that represents its psychophysical effect on a viewer. We propose a new two-step greyscale transformation that combines a global mapping based on perceived lightness with a local chromatic contrast enhancement. Our simple algorithm yields comparable images to more complex approaches, and its linear runtime makes it suited to video processing and accelerated graphics hardware implementations. Decomposed into two stages, this approach mimics aspects of the human visual system, which processes global attributes while simultaneously depending on local contrasts such as edges and surrounds.

This join project, done with Kaleigh Smith and Karol Myszkowski, was accepted for publication in the *Eurographics 2009* conference, and published in the *Computer Graphics Forum* journal [21].

6.3.6. Diffusion Curves

Participants: Adrien Bousseau, Alexandrina Orzan, Joëlle Thollot.

Compared with raster graphics, vector graphics offers a more compact representation, resolution-independence (allowing scaling of images while retaining sharp edges), and geometric editability. Vector-based images are more easily animated (through keyframe animation of their underlying geometric primitives), and more readily stylized (e.g. through controlled perturbation of geometry). For all of these reasons, vector-based drawing tools, such as Adobe Illustrator©, CorelDraw©, and Inkscape©, continue to enjoy great popularity, as do standardized vector representations, such as Flash and SVG.



Manually drawn. Automatic vectorization.

Figure 16. Using diffusion curves to generate high quality vector graphics.

However, for all of their benefits, vector-based drawing tools offer only limited support for representing complex color gradients (most vector formats support only linear and radial gradients), which are integral to many artistic styles.

We propose a novel vector-graphics primitive, called the diffusion curve. A diffusion curve is a curve that diffuses colors on both sides of the space that it divides. The motivations behind such a representation are twofold. First, most color variations in an image can be assumed to be caused by edges (material and depth discontinuities, texture edges, shadow borders, etc.). Second, this representation supports traditional freehand drawing techniques. In a typical drawing session with our tool, the artist first lays down drawing curves corresponding to color boundaries. In contrast with traditional vector graphics, the color boundaries do not need to be closed and may even intersect. A diffusion process then creates smooth gradients on either side of the curves. By specifying blur values along a curve, the artist can also create smooth color transitions across the curve boundaries.

This collaboration with Pascal barla, Holger Winnemöller and David Salesin was rewarded by a *SIGGRAPH 2008* presentation, published in the *ACM Transaction on Graphics* journal [18].

6.3.7. Vector Art from 3D Models

Participant: Elmar Eisemann.

The strokes and fills of vector graphics more closely match the traditional tools of art and design, and vector graphics have become the preferred medium for the stylized illustrations that help visually communicate ideas and concepts in the form of “clip-art” libraries. But even though their digital representation (e.g. layered filled 2D polygons) is simple, constructing a vector illustration requires technical skills beyond those of the typical consumer, creating a demand for a rendering system that converts a 3D meshed polygonal surface model into a customized and stylized illustration with little to no user-input.

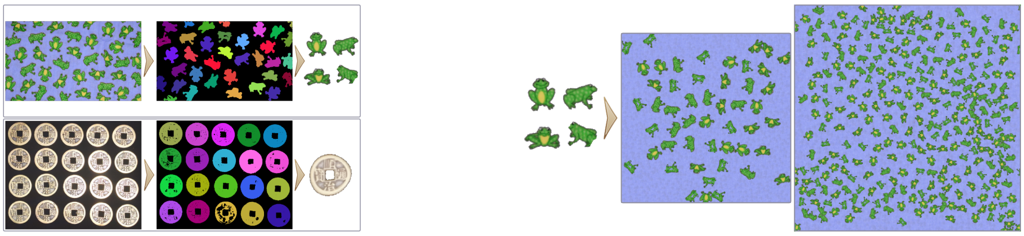
We develop a new method that directly renders a 3D meshed surface model into stylized filled-region vector art consisting of layered 2D polygons. The most difficult part of this process is the identification, processing and stylization of the regions defined by using the meshed object’s contours as a boundary representation. This rendering approach requires several new contributions. We define smooth contours that properly surround regions with the novel combination of a jagged visual contour, smooth shading contours, cast jagged shadow volumes and a new adjusted smooth shadow contour. We analyze and decompose the vector-art rendering process into geometric and topological components. We extend an existing programmable contour stylization method with new features that capitalize on the region definitions, including styles that offset the region from the contour, small region elision, region-sensitive contour smoothing and fill processing.

The details of the complete pipeline – developed in collaboration with Holger Winnemöller, John C. Hart and David Salesin – were published at the *19th Eurographics Symposium on Rendering* [16]

6.3.8. Pattern-Based Texture Analysis and Synthesis

Participants: Pierre-Edouard Landes, Cyril Soler.

In this research [37], we found a new method for the analysis and resynthesis of a specific class of textures, that we refer to as ”high-level stochastic textures”. Such textures consist of distributions from different and potentially overlapping shapes, or ”patterns”. The constituent distributions may be random or they may obey some geometric placement rule. As a result they fall into the class termed, high-level stochastic textures, that comprises both arrangements of 2d primitives as well as near regular textures.



(a) (b)

Figure 17. Our method proposes a complete framework for the analysis (a) and resynthesis (b) of pattern-based textures. Once the patterns have been detected and extracted thanks to their repetition throughout the input sample (a), synthesizing new textures preserving such relevant shapes becomes straightforward (b).

Our proposed method first aims at extracting and capturing the distribution of relevant shapes. To achieve this, we rely on their repetition throughout the input sample. Once this analysis step is performed, it then becomes possible to resynthesize visually similar and tileable textures by reusing the obtained patterns. This is in complete contrast to classic pixel-based Markovian approaches, where such long-range structure preserving synthesis is hard if not impossible.

6.3.9. Digital Halftoning

Participant: David Vanderhaeghe.

Digital halftoning is a well-established technique for visualization of continuous tone or rich multiple tone images on visualization devices having very limited range of available tones. Driving printing devices is a typical application for digital halftoning algorithms. Most of the current halftoning algorithms produce printable images, adapted for a specific device. We concentrate in this work on dithering which commonly use threshold matrices. Matrices are chosen essentially for commodity: they are simple to store and to manipulate.

We propose to demonstrate that dither structures other than matrices can be advantageously used for the tasks where threshold matrices are usually employed. The structure we use is rectifiable polyominoes, a choice inspired by Ostromoukhov in 2007. A second important source of inspiration is the void-and-cluster method, we use the simple and tractable optimization process describe by Ulichney in 1993. The main idea of this paper is rather simple: to replace square matrix of threshold values by a on-rectangle structure, which contains approximately the same number of threshold values that as dither matrix. We propose to use rectifiable polyominoes: simple non-square figures which tile the Euclidean plane without gaps. The threshold values associated with the polyominoes can be optimized once forever, store in lookup tables and inexpensively used during the image generation.

This work completed successfully with Victor Ostromoukhov has been published at the *International Conference on Computer Graphics and Visualization* [35].

6.3.10. Real-Time Coherent Stylization

Participants: Pierre Bénard, Adrien Bousseau, Joëlle Thollot.

Many non-photorealistic rendering approaches aim at depicting 3D scenes with styles that are traditionally produced on 2D media like paper. The main difficulty suffered by these methods is temporal coherence when stylizing dynamic scenes. This problem arises from the contrary goals of depicting a 3D motion while preserving the 2D characteristics inherent to any style marks (pigments, strokes, etc). Achieving these goals without introducing visual artifacts implies the concurrent fulfilment of three constraints. First, the style marks should have a constant size and density in the image in order to preserve the 2D appearance of the medium. Second, the style marks should follow the motion of the 3D objects they depict to avoid the sliding of the style features over the 3D scene. Finally, a sufficient temporal continuity between adjacent frames is required to avoid popping and flickering.

We propose dynamic textures, a method that facilitates the integration of temporally coherent stylization in real-time rendering pipelines.This method uses textures as simple data structures to represent style marks. This makes our approach especially well suited to media with characteristic textures (eg. watercolor, charcoal, stippling), while ensuring real-time performances due to the optimized texture management of modern graphic cards. Central to our technique is an object space infinite zoom mechanism that guarantees a quasi-constant size and density of the texture elements in screen space for any distance from the camera. This simple mechanism preserves most of the 2D appearance of the medium supported by the texture while maintaining a strong temporal coherence during animation.

This work was awarded by the *best paper price* during the 21th AFIG conference [36] and has been accepted for publication at the ACM Symposium I3D 2009 [30].

7. Contracts and Grants with Industry

7.1. CIFRE with Eden Games

Participants: Lionel Atty, Nicolas Holzschuch [contact], François Sillion.

We have a student doing a PhD thesis in cooperation with the video games company Eden Games, located in Lyon. This PhD thesis is supported by the french “CIFRE” program. The PhD student, Lionel Atty, now in his third year, is working on rendering photorealistic effects, such as soft shadows, in real-time.

7.2. GENAC 2

Participants: Olivier Hoel, Nicolas Holzschuch [contact], Frank Rochet, Cyril Soler.

We have started a cooperative research work with two video game companies in Lyon, Eden Games and WideScreen Games, in cooperation with the EVASION research team of INRIA Rhône-Alpes and the LIRIS research laboratory 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 global illumination in real-time for video games. This project started in September 2007, for 24 months.

7.3. Cooperation with Adobe Research Center

Participants: Elmar Eisemann, Alexandrina Orzan.

We have started a cooperation with David Salesin of the Adobe Research Center in Seattle. This cooperation has resulted in extended stays of Alexandrina Orzan in Seattle, one publication in common [18], and gifts from Adobe Company for the research activity in ARTIS.

8. Other Grants and Activities

8.1. ANR Blanc: HFIBMR

Participants: Nicolas Holzschuch, Lionel Baboud.

We are funded by the ANR research program “Blanc” (research in generic directions) for a joint research work with the Jean Ponce (Ecole Normale Supérieure) and Adrien Bartoli (University Blaise Pascal — Clermont II), on acquisition, modelling and rendering of Image-Based Objects, with a focus on high-quality and interactive rendering. This grant started in September 2007, for 36 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.

8.3. ANR RIAM: CHEVEUX

Participants: Joëlle Thollot, Hedlena Bezerra.

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 dAlembert de lUniversité 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: Joëlle Thollot, David vanderhaeghe, Adrien Bousseau.

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. GRAVIT

Participant: Nicolas Holzschuch.

GRAVIT is a Rhône-Alpes region consortium aiming at helping research results in order to help them reach industry levels, typically by supporting the development of platforms.

ARTIS is supported by the GRAVIT consortium, through the GVTR project (*GeoVisualisation en Temps Réel*), in cooperation with the EVASION and REVES project-teams at INRIA. Our goal is to obtain a real-time rendering engine for very large virtual worlds, potentially infinite. The project was initially granted in October 2006, for a period of one year, but was later extended to August 2008. We started with the platform developed for the NatSim project by the EVASION project-team, and extended it to open the API to ease the integration of new modules.

8.6. 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.

8.7. Association with MIT CSAIL graphics group

Participants: Adrien Bousseau, Nicolas Holzschuch, Emmanuel Turquin.

INRIAs office of international relations has set up in 2001 a program for associated teams that bring together an INRIA project-team and a foreign research team, providing a form of institutional recognition to stable scientific collaborations involving several researchers on each side.

An associated team was created for the 2003-2005 period between ARTIS and the MIT graphics group (CSAIL Lab) on the subject of Flexible Rendering. It has been extended for 2006, 2007 and 2008. This association, now in its sixth year, has been extremely positive: several research actions (described above in the results sections) have been performed jointly with MIT researchers.

The associated team has helped this collaboration on a practical level by providing funding for researcher exchanges. The two teams know each other very well and frequent visits and conference calls make actual cooperation a reality (for instance publications [42], [44], [46], [45], [47], [43] are co-signed by researchers from the two groups).

The activity of the associate team in 2008 focused on the following three items:

- Emmanuel Turquin was working jointly with Jaakko Lehtinen on Meshless Finite Element Methods for Global Illumination (section 6.1.1). This was following his stay at MIT in December 2007; this work has resulted in a publication at *SIGGRAPH 2008* [17].
- We continued our research project on the frequency analysis of light transport, with an emphasis on the development of practical algorithms for the evaluation of frequency spectra in photon tracing. This work has resulted in a paper accepted for publication in ACM Transactions on Graphics [22].
- Adrien Bousseau conducted a long term stay at MIT (3 months), working with Fredo Durand on Computational Photography. They are working on the separation of a photograph in two composants: lighting and color. This work offers many potential applications for image editing softwares, and we are cooperating with the Adobe Research center in Boston, especially with Sylvain Paris, a former ARTIS Ph. D. student. This work is expected to result in a common publication over the year 2009.

8.8. Exploradoc grants at nVidia, London, UK

Participant: Cyril Crassin.

The Region Rhône-Alpes has established a grant program to help PhD students in starting actual international cooperation during their PhD years, with support for a six month stay in a lab in a foreign country.

Cyril Crassin obtained a founding for a six month stay at *n*Vidia-R&D, UK, to work on adaptation of data structures and algorithms to high-performance computing on GPU (which *n*Vidia is the world leader constructor).

8.9. Internship INRIA

Participant: Kartic Subr.

INRIA has established an internship program to finance stays from foreign students in INRIA research programs. Kartic Subr, from the University of California at Irvine, is staying at the ARTIS research project for six months, funded by the INRIA internship program, from October 2007 to March 2008, working with Cyril Soler and Nicolas Holzschuch on Frequency Analysis of Light Transport for Photon Mapping.

It leads to an accepted journal paper in *ACM Transactions on Graphics* [22].

8.10. Sabbatical INRIA

INRIA has established a Sabbatical program to encourage mobility by researchers. Nicolas Holzschuch is staying at the Department of Computer Science of Cornell University, for 12 months from July 2007 to July 2008, funded by this program.

8.11. Collaboration with Rutgers University, USA

Participant: Hedlena Bezerra.

Hedlena Bezerra was invited for 6 months at Rutgers University, working directly with professor Doug DeCarlo and under supervision of Dr. Joëlle Thollot. During the stay, the main problems related to the derivation of 3D normal maps from 2D animated line drawings were raised. The collaboration resulted in the development of a system to infer normal information on 2D character's outlines (see figure 18a) and interpolate them over the remaining image in order to obtain a surface normal map (18b). The goal of this project is to provide controllable and temporal coherent normal maps that can be used into the animation process to improve shading (18c). A joint publication is in progress, and should be submitted in a few weeks.

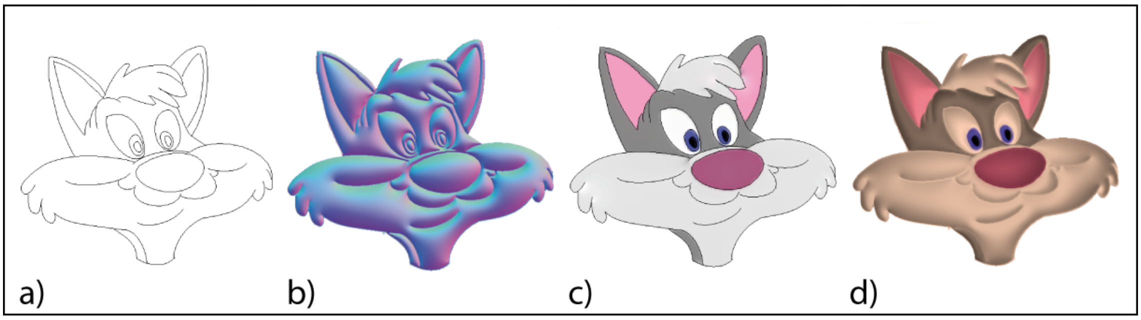


Figure 18. The shading process. a)Normal information is derived on the character's outlines. b) A interpolation process creates a surface normal map. c) Color map given by the user. d) Using the normal and color maps, the character is illuminated as it were a 3D object living in a 3D illuminated environment (called the shading process).

9. Dissemination

9.1. Thesis and HDR defended in 2008

9.1.1. PhD Thesis: Elmar Eisemann

A rapidly growing computer graphics community has contributed to dramatic increase in complexity with respect to geometry as well as physical phenomena. Simulating, approximating and visualizing geometry consisting of tens of millions of polygons simultaneously tested for collision or visibility is becoming increasingly common. Further, recent technological innovations from graphics card vendors has given impetus to achieving these results at very high frame rates. Despite tremendous developments in graphics hardware, capturing the complete surrounding environment poses a significant challenge. Given the added time constraint for real-time or interactive rates, simplified representations and suitable approximations of physical effects are of key importance.

Elmar's dissertation[10] focuses on simplified representations and computations to achieve real-time performance for complex tasks and concentrates on a variety of topics including simplification, visibility, soft shadows and voxelization.

9.1.2. PhD Thesis: David Roger

Specular and glossy reflections are very important for our perception of 3D scenes, as they convey information on the shapes and the materials of the objects, as well as new view angles. They are commonly rendered using environment maps, with poor accuracy. We have designed more precise algorithms, under the constraints of interactive rendering and dynamic scenes, to allow applications such as video games or dynamic walk-through.

In the thesis [11], we propose two methods for specular reflections. The first relies on rasterization and computes the position of the reflection of each vertex of the scene, by optimizing iteratively the length of the light paths. Then, the fragment shader interpolates linearly between the vertices. This method can represent parallax and all view dependent effects, and is better suited to smooth and convex reflectors. The second is a GPU ray tracing algorithm using a hierarchy of rays: the primary rays are rendered with rasterization, and the secondary rays are grouped hierarchically into cones to form a quad-tree that is rebuilt at each frame. The ray hierarchy is then intersected with all the triangles of the scene in parallel. That method is slightly slower, but more general and more accurate. We have extended this ray tracing algorithm to cone tracing supporting glossy reflections and continuous anti-aliasing.

The ray and cone tracing techniques have been implemented under the stream processing model in order to use the GPU efficiently. In that context, we developed a new hierarchical stream reduction algorithm that is a key step of many other applications and has a better asymptotic complexity than previous methods.

9.1.3. PhD Thesis: David Vanderhaeghe

David's thesis [13] deals with graphic primitives distributions in two different domains: expressive rendering and printing system. To distribute is to position objects into a space. We focus on two dimensional space distributions. Moreover, a distribution follow an importance function describing the density of objects locally wanted for each point of the considered space. The quality of the distribution is judged by the observation of the position of the object, using spectral analysis for instance.

In the field of expressive rendering, we focus on distribution for animated stroke-based rendering. Stroke-based rendering is used to obtain images that mimic some natural medias like painting. In our approach, we obtain the animation by moving the stroke from one frame to the other. When we do that, we need to follow an input motion, a given importance function and to correctly represent the targeted style. We call temporal coherence the trade-off made between this three conflicting constraints. We propose a complete system for animated stroke-based rendering with several distribution algorithms following the input motion and the importance function, and also with control of the rendering style.

For printing system, we propose a distribution method for dot of ink. The method produces perceptually pleasant distribution while staying sufficiently efficient to be implemented in printers available nowadays.

9.1.4. HdR Thesis: Joëlle Thollot

The visual communication is an efficient way to communicate a message. Depending on the goal of the image's author, various representations can be chosen going from photographs, illustrations, paintings to very schematic. Joelle's HDR [12] presents some computer graphics tools developed to enhance the result of an image creation process. Such a process can be a 3D rendering, a film or a photograph filtering, or a drawing from scratch.

The underlying principles of this body of work are twofold. First it is fundamental to find a good compromise between automatic and manual production. For that, the user always has to stay in the loop and careful attention has to be paid on the way the user can interact with the system. Second, an image is made to be seen by a human. It is therefore possible to refer to the visual perception knowledge to guide the algorithms.

9.2. Cooperation with LyonGame

Artis is developing its links with the gaming industry in Rhone-Alpes by taking an active part to the exchanges and collaborations piloted by the *Lyon Game* Association. This association, which is granted a "Pôle de compétitivité" works actively to favor game-related business development and academic collaboration between studios and laboratories. Through it, Artis has a CIFRE Phd student Lionel Atty co-directed with Eden Games and working on real-time realistic rendering (see section 7.1). Three researchers are working with Phoenix Interactive, either for short-term consulting or for long-term research projects. One Phd student, Thierry Stein, has started his research on a subject defined after discussion with the game designer of Phoenix, Marc Albinet. Xavier Décoret was a member of the scientific committee of the "Pôle de compétitivité".

9.3. Scientific diffusion and Education

The proper diffusion of scientific results is an important part of their value. Since most of this diffusion is done using the web, a new bibliography server has been developed to ease this diffusion [13]. A search engine browses all the publications: download is made easy, and all associated documents (images, videos, abstract, bibTex...) are also available. This kind of local bibliographic tool is not widely spread in the academic community, and we tried to make our system easy to distribute (see section 5.6), so that it can be shared.

Most of the members of the team (faculty members as well as Ph. D. students) give courses. This educational effort is also present in the distribution of libraries such as libQGLViewer, which have a real pedagogical interest since they simplify and explain the creation of computer graphics images. The project is also involved in the animation of the "*Fête de la Science*" (scientific vulgarization event), and is often consulted for its scientific expertise.

9.4. Other activities

- Nicolas Holzschuch is:
  - Member of the program committee of EGSR 2008 and EG 2009,
  - Member of the program committee of Pacific Graphics 2008,
  - Member of the "Commission d'evaluation" of INRIA.
- Joëlle Thollot is:
  - Member of the program committee of EG 2008, and NPAR 2009,
  - Chair of NPAR 2008 Animation Session,
  - Member of the "Commission de Spécialistes" of INPG,
  - Member of the "Commision de sélection" of INRIA Bordeaux.
- Elmar Eisemann is:
  - Member of the program committee of EGSR 2009.

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