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Project-Team artis

Acquisition, Representation and Transformations for Image Synthesis

Rhône-Alpes

THEME COG

Activity Report

2006

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1. Team

ARTIS is both an INRIA project-team and a subset of the GRAVIR joint research lab of CNRS, Institut National Polytechnique de Grenoble (INPG), INRIA and Université Joseph Fourier Grenoble-I (UJF). The GRAVIR laboratory is part of the IMAG federation (Institut d'Informatique et de Mathématiques appliquées de Grenoble).

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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 and Illustration. 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: François Sillion, Cyril Soler, Nicolas Holzschuch, Jean-Marc Hasenfratz, Emmanuel Turquin, Samuel Hornus, David Roger, Lionel Atty.

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") multiresolution 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

Keywords: *Global illumination*, *inverse rendering*, *multiresolution*.

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: François Sillion, Joëlle Thollot, Cyril Soler, Pascal Barla, David Vanderhaeghe, Matt Kaplan, Hedlena Bezerra, Adrien Bousseau, Pierre-Edouard Landes, Kaleigh Smith, David Lanier, Florent Moulin.

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 diffferent 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. Geometric calculation and model transformation

Participants: François Sillion, Cyril Soler, Nicolas Holzschuch, Xavier Décoret, Samuel Hornus, Elmar Eisemann, Aurélien Martinet, Lionel Baboud, Thierry Stein.

Geometric models of a 3D scene are available from a variety of sources, including industrial partners. In our experience, more 3D geometry files lack all forms of high level information, either because it was lost during format conversions, or because it was not defined by the designer of the model. On the other hand, most researchers working with 3D scene data would like to use such high level information such as which groups of polygons form connex shapes, human regognisable objects, have symetries, or even which groups of polygons look like each other (also known as *instancing information*). We are working on algorithms to automatically retrieve some high level (also named *semantic*) information from a *polygon soup*, *i.e* a list of polygons without any information about how these polygons are related to each other.

Creating images from three-dimensional models is a computationally –intensive task. A particularly difficult issue has long been the calculation of visibility information in 3D scenes. We are working on several issues related to visibility, such as the decomposition of a scene into appropriate regions (or cells) to assist in the precalculation of visibility relationships, or the precalculation of object sets visible from a particular view point or region of space.

More generally, we are interested in all aspects of geometric calculation that lead to the creation, simplification or transformation of 3D models. Complex scenes for virtual environments are typically assembled using data from very different sources, therefore coming in very different resolutions or amounts of detail. It is often a requirement to suppress unneeded detail in some parts of the scene, or to generate detail where it is missing. Given the very high cost of manual modeling, fully or semi-automated techniques are essential.

Furthermore, the apparent complexity and the amount of detail should also be adapted to the particular usage in the application, and we advocate that this can be realized by choosing appropriate data representations. We are therefore working on innovative data representations for 3D scenes, notably involving many image-based techniques.

3.5. Virtual and mixed realities

Participants: François Sillion, Jean-Marc Hasenfratz, Jean-Dominique Gascuel, Alexandrina Orzan.

Mixed reality Set of techniques involving the addition of real elements to a virtual world, or virtual elements to the real world

Convergence of real and synthetic imagery becomes a reality a few years ago, with the availability of high-quality 3D graphics and real-time video input on consumer-grade computer. One fundamental issue in mixing real and synthetic imagery lies in the proper combination of the two image sources. Our focus is on the lighting and shadow consistency: Making sure that lighting effects are consistent between the synthetic and real parts of the image remains a challenge, especially for real-time applications.

3.5.1. Cyber-II

In the context of Augmented Reality, the goal of Cyber-II[1] project is to simulate, in real-time, the presence of one or more persons (*e.g.* a TV presenter and his guests, or a teacher) in a virtual environment. This simulation consists mainly in visualizing the combined scenario, and possibly in providing tools for interaction between the real person, the virtual environment, and the observer (*e.g.* TV spectator or pupil).

For that we need an integration of the actors as realistic as possible and an interaction between the actors and the virtual environment in real time (*i.e.* 25 frames per second).

In order to achieve a realistic immersion, we have to compute how the actor is re-lighted by the virtual lights and the way he casts shadows on the virtual objects. To do this, a 3D model is necessary. Moreover, a realistic appearance of the integrated persons is needed, and we propose to use real-world images to texture the virtual model.

The main overall technical requirements are thus a highly realistic visualization, which works in real time. We have proposed new methods to capture an actor with no intrusive trackers and without any special environment such as a blue-screen set, to estimate its 3D-geometry and to insert this geometry into a virtual world in real-time. We use several cameras in conjunction with background subtraction to produce silhouettes of the actor as observed from the different camera viewpoints. These silhouettes allow the 3D-geometry of the actor to be estimated by a voxel based method. This geometry is rendered with a marching cube algorithm and inserted into a virtual world. Shadows of the actor corresponding to virtual lights are then added and interactions with objects of the virtual world are proposed.

The main originality of this work is to propose a complete and scalable pipeline that can compute up to 30 frames per second. It has been published in the "Vision, Video and Graphics" workshop [33] and a more interactive version has been published in "Virtual Environments" [34].

[1] The CYBER-II project is supported by the ACI "Masse de données" of the French Department of Research.

3.6. Guiding principles

We base our research on the following principles:

3.6.1. 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.

3.6.2. Balance between speed and fidelity

We seek to develop representations affording a controllable balance between these conflicting goals. In particular this applies to multiresolution 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.

3.6.3. 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 analyse 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.

3.6.4. 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 [36]).

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.

4.4. Mixed Reality

A system that allows to seamlessly blend virtual images generated by a computer and a video stream recorded by a digital camera (*e.g.* a live footage) would have many applications.

In a *virtual studio*, a TV speaker or a teacher is shot in a blue screen environment, and is shown interacting with a fine looking environment. *Virtual prototyping* enable to review complex project avancements, using various representations, and possibly on multi-sites setups. *Virtual medecine* enables to do repetitive riskless training, or to easily build powerfull rehabilitation setups. *Virtual archeology* or *achitecture* enables to visit past or futur constructions. Specific styles can be used to show various hypothesis, and real-time manipulation is a powerfull interface to interact with the data base.

5. Software

5.1. Introduction

ARTIS insists on sharing the software that is developped 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[2].

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

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: Samuel Hornus, Joëlle Thollot.

The MobiNet software allows creation of simple applications such as video games or pedagogic illustrations relying on intuitive graphical interface and language allowing to program a set of mobile objects (possibly through a network). This software is available in public domain for Linux and Windows[3] and made in collaboration with the EVASION INRIA project. The main aim is pedagogical: MobiNet allows young students at high school level with no programming skills to experiment with the notions they learn in math and physics by creating simple video games. This platform was massively used during the INPG "engineer weeks": 150 senior high school pupils per year, doing a 3h practice. This work is partly funded by INPG. Various contacts are currently developed in the teaching world. Finally, mobinet was decribed in a publication at the Eurographics conference [37] in 2004.

5.6. Basilic : an Automated Bibliography Server

Participant: Gilles Debunne [contact].

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[4].

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 garanteeing 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[5]

5.7. XdkBibTeX : parsing bibtex files made easy

Participant: Xavier Décoret [contact].

[3] http://www-evasion.imag.fr/mobinet/index.en.html
[4] See for instance http://artis.imag.fr/Publications
[5] http://artis.imag.fr/Software/Basilic

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[6]

6. New Results

6.1. Lighting and rendering

Participants: François Sillion, Cyril Soler, Nicolas Holzschuch, Jean-Marc Hasenfratz, Emmanuel Turquin, Samuel Hornus, David Roger, Lionel Atty.

6.1.1. Application of frequency analysis of light transport to photon mapping

In 2005, we derived a complete framework for the analysis of light transport in Fourier space, providing the necessary tools and equations which permit to compute frequency informations of the distribution of light in a scene [28]. Lately, in 2006, we have been working on the application of these principles to some specific lighting simulation techniques, starting with *photon mapping*.

Whereas the main idea of photon mapping is to transport light as a density of light particles of unit energy, we also carry frequency information in photons such that it is additionnaly possible to reconstruct frequency information in the computed image. Such information permits to foresee some hard-to-predict phenomena such as the presence of shadows, the amount of bluring due to depth of field or the low variation of light across diffuse surfaces, in the specific lighting conditions of the computed image.

The application of such a scheme is to optimaly adapt the sampling in pixel space as well as in angular space (for secondary reconstruction ray) so as to avoid calculations that would ordinary be made necessary by the absence of a correct clue on frequencies, yet not necessary for the image itself. The ongoing work already provides some interesting and promising results, as showed on Figure 1.

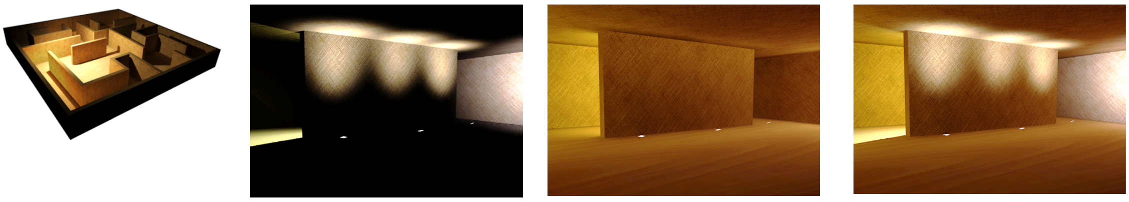
Figure 1. Left: a simple configuration where blockers are the cause of high frequencies of the lightfield onto the receiving surface. The blue square shows a clue of what the spectrum in space and angles looks like. Right: from the spectrum, a correct sampling density for the image is produced, which allows to allocate an optimal amount of cpu time to the computation of the shadow onto the receiver.

[6] http://artis.imag.fr/Membres/Xavier.Decoret/resources/xdkbibtex/

6.1.2. Wavelet Radiance Transport for Interactive Indirect Lighting

We have developed an algorithm for real-time simulation of indirect lighting. Combined with a separately computed direct lighting, our algorithm gives interactive global illumination in dynamic scenes.

We start by computing the global transport operator (GTO), expressing the converged indirect lighting as a function of direct lighting. This GTO is computed and expressed in a hierachical manner, using a new multi-dimensional wavelet basis we have developed.



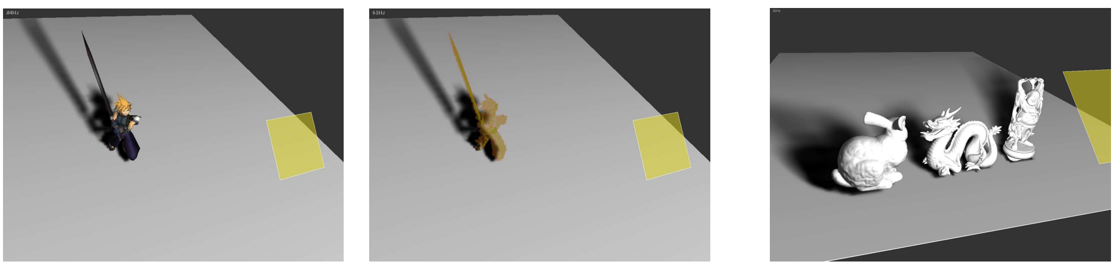
(a) Maze scene (b) Direct lighting (c) Indirect lighting computed with our algorithm (d) Resulting global illumination

Figure 2. Our interactive global illumination algorithm. This scene runs at 15 fps.

At runtime, we compute the projection of direct lighting onto this wavelet basis, then apply the GTO to the projection. We thus get the indirect lighting. This indirect lighting is then added with a direct lighting component computed on the GPU, giving interactive global illumination. This technique allows unprecedented freedom in the interactive manipulation of lighting for static scenes (see Figure 2). Our work, done in cooperation with Janne Kontkanen, of the Helsinki University of Technology, has been published at the 2006 Eurographics Symposium on Rendering [20].

6.1.3. Real-Time Soft Shadows using Shadow Maps

We have developpped a completely new algorithm for real-time computation of soft shadows. This algorithm is based on the shadow map method [39]. The shadow map is converted into a discrete representation of the occluders (see Figures 3a and 3b), and we compute the soft shadow of this discrete representation.



(a) The original model (b) The discretized occluder (c) Our largest test scene (565,203 polygons, renders at 20 fps)

Figure 3. Our real-time Soft Shadow algorithm, based on shadow maps.

Through several optimisations, and the use of programmable graphics hardware, we achieve a very efficient rendering of soft shadows, even on complex scenes. The algorithm scales well with the number of occluders and the complexity of the scene (see Figure 3c). The algorithm achieves faster results for large penumbra regions, exploiting the fact that they are low-frequency effects.

We have conducted an extensive testing of our algorithm, comparing it with other soft-shadow algorithm and ground truth. The description of the algorithm, along with the extensive testing has been published in *Computer Graphics Forum* [3].

6.1.4. Precomputed Ambient Occlusion

Ambient occlusion is used widely for improving the realism of real-time lighting simulations, in video games and in special effects for motion pictures.

(a) Example of proximity shadows, computed using our algorithm for ambient occlusion. This scene runs at more than 200 fps.

(b) Using the Ambient Occlusion information to compute illumination from an environment map. This scene runs at 30 fps.

Figure 4. Our method for precomputed ambient occlusion greatly improves the realism of the scenes rendered in real-time, giving contact shadows and illumination from environment maps at a very low cost.

We have developped a new, simple method for storing ambient occlusion values, that is very easy to implement and uses very little CPU and GPU resources. This method can be used to store and retrieve the percentage of occlusion, in combination with the average occluded direction.

This information is used to render occlusion from moving occluders, as well as to compute illumination from an environment map at a very small cost (see Figure 4).

The speed of our algorithm is independent from the complexity of either the occluder or the receiver, making our algorithm highly suitable for games and other real-time applications. This work has been accepted for publication in the *Journal of Graphics Tools* [7].

6.1.5. Real-Time Reflexions on Curved Surfaces

We have developed an algorithm for real-time simulation of reflexions on specular surfaces. We separate the reflector from the rest of the scene, then introduce a new projection function, corresponding to the effect of the reflector on the objects in the scene. For curved reflectors, this projection function is not linear and difficult to compute, but we have shown that it is possible to approximate using the programmability of the graphics card. This work has been published at the Eurographics 2006 conference [10].

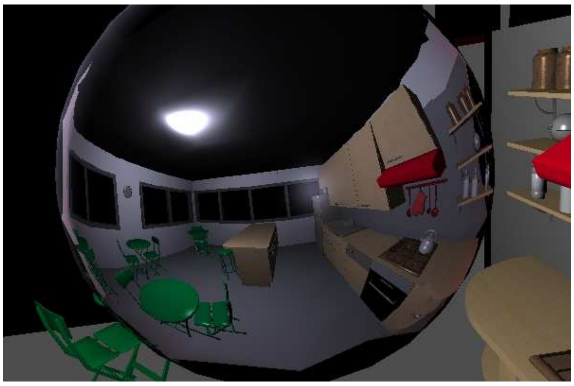


Figure 5. Example of reflexions computed in real-time using our algorithm.

6.1.6. Modelling and Rendering of Geometry with Relief Textures

We have developed a way to render geometry using an image based representation. Geometric information is encoded by a *texture with depth* and rendered by rasterizing the bounding box geometry (see Figure 6). For each resulting fragment, a shader computes the intersection of the corresponding ray with the geometry using pre-computed information to accelerate the computation. Great care is taken to be artifact free even when zoomed in or at grazing angles. We integrate our algorithm with reverse perspective projection to represent a larger class of shapes. The extra texture requirement is small and the rendering cost is output sensitive so our representation can be used to model many parts of a 3D scene (see Figure 7). The paper has been published at Graphics Interface 2006 conference [14].

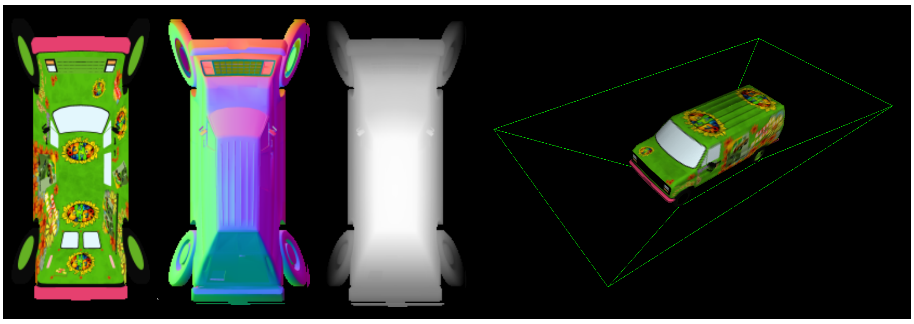


Figure 6. (left) Color, normal and depth textures for a perspective distorted heightfield (right) Rendering of the bounding box with ray-intersection performed in a shader.

Although other methods have been published in the litterature for rendering heightfields on the GPU, our method was the first one to focus on exactness. Consequently, it can be used to model any heightfields, no matter the amplitute and screen size of the feature it contains. Thus, it can be used to render macro objects, as opposed to micro details. We continued the work by exploring classes of objects that fit in the heightfield category.

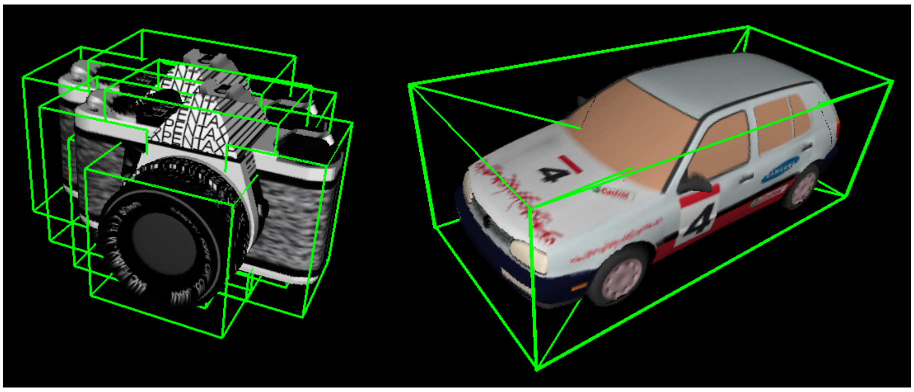


Figure 7. Rendering of an object represented by 6 relief textures.

6.1.7. Realistic Water Volumes in Real-Time

Water surfaces over basins, ponds and alike have been investigated. We extended the method of previous section to handle simultaneously two heightfields (one for the water surface and one for the bottom of the ground). Because we do ray-tracing, complex effects such as diffraction, absorption, etc. can be easily integrated. We also incorporated simple GPU based photon mapping to compute caustics. Combining all this, we are able to render realistic water in real time, fully on the GPU (Figure 8). The results were published at Symposium on Natural Phenomenae '06[13].

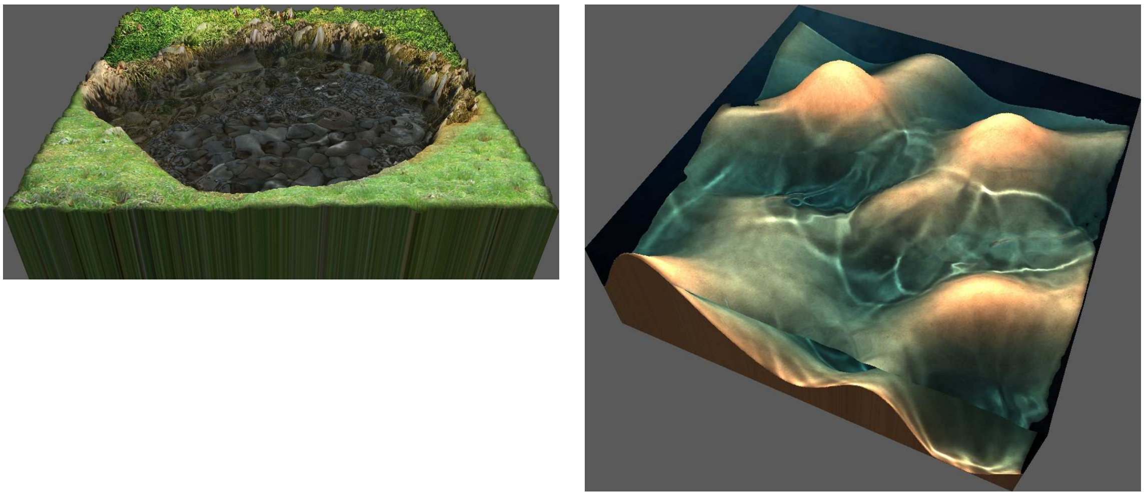


Figure 8. Rendering of water surfaces.

6.2. Visibility

Participants: François Sillion, Gilles Debunne, Xavier Décoret, Denis Haumont, Elmar Eisemann, Samuel Hornus.

6.2.1. Fast Scene Voxelization and Applications

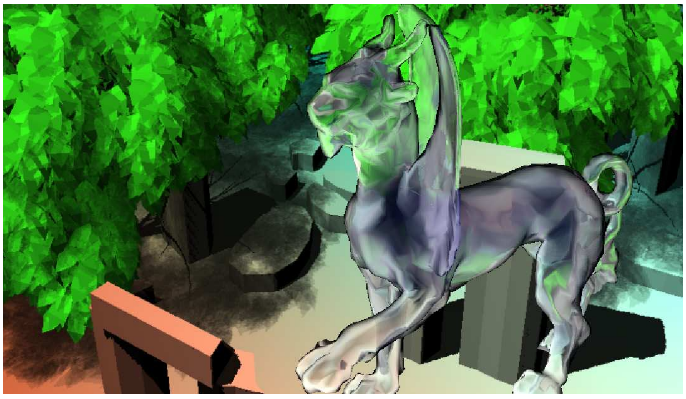


Figure 9. Voxelization on standard graphics hardware allows for rapid, high quality effects

In this approach standard graphics hardware is used to dynamically calculate a voxelized representation of the scene, optimized for current cards and and involving minimal data transfer. Voxels are a simplified representation of the scene in form of a constant number of information with respect to a chosen resolution.

Until now, the creation of such a structure remained expensive. Using our approach 1,000,000 polygons can be voxelized in the order of milliseconds.

Several applications arise; like attenuation by semi-transparent materials, volume estimation for refraction and scattering and fast, high quality shadow calculation (culling / clamping for shadow volumes).

The technique is especially promising, as the announced features of the next generation graphics hardware will be highly adapted to our approach. The paper has been accepted to I3D 2006 [17]. It has been selected for re-publication as a sketch at Siggraph [18].

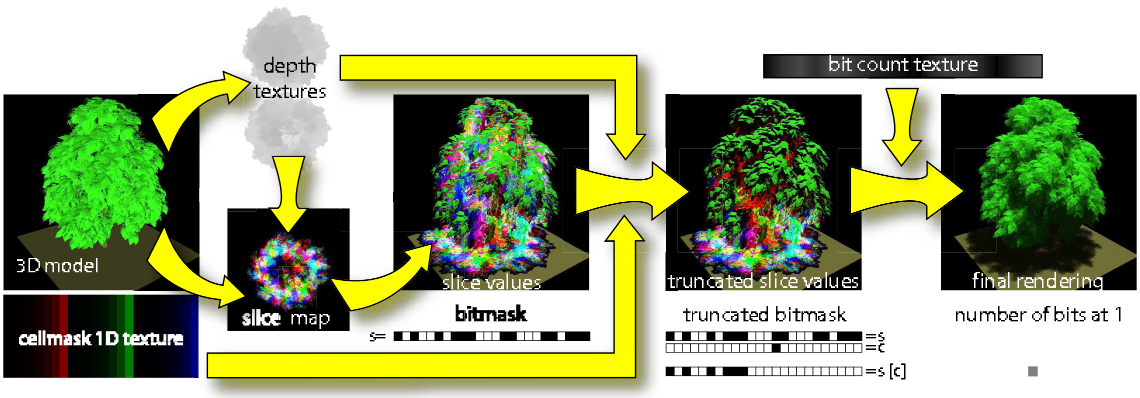


Figure 10. Estimation of attenuation inside foliage based on the voxelization (≈ 30 fps)

6.2.2. Plausible Image Based Soft Shadows Using Occlusion Textures

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. 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 11) on arbitrary scenes (complex geometry, high polygon count, animated scenes) very fast, with all computations taking place on GPU. The result have been published at Sibgrapi [19] and has been selected for re-publication as a journal paper at CGF (acceptance is on its way).

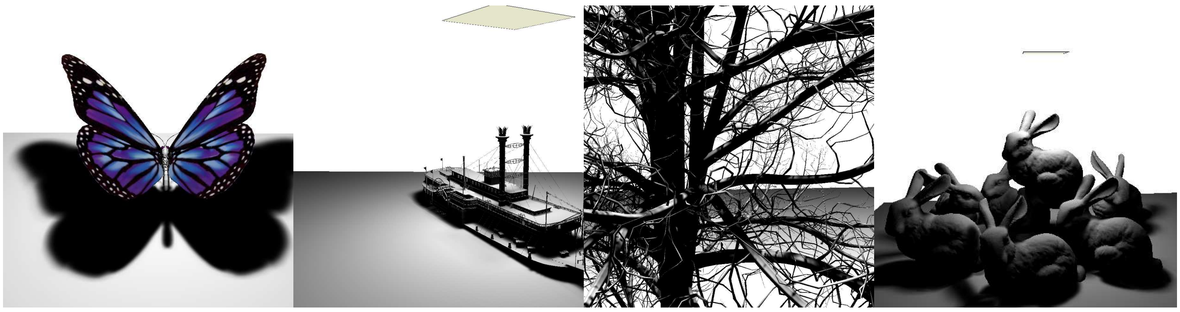


Figure 11. Plausible soft shadows

6.3. Expressive Rendering

Participants: François Sillion, Joëlle Thollot, Cyril Soler, Pascal Barla, David Vanderhaeghe, Matt Kaplan, Hedlena Bezerra, Adrien Bousseau, Pierre-Edouard Landes, Kaleigh Smith, David Lanier, Florent Moulin.

6.3.1. Interactive watercolor rendering

Watercolor offers a very rich medium for graphical expression. As such, it is used in a variety of applications including illustration, image processing and animation. The salient features of watercolor images, such as the brilliant colors, the subtle variation of color saturation and the visibility and texture of the underlying paper, are the result of the complex interaction of water, pigments and the support medium.

In this work, we present a set of tools for allowing the creation of watercolor-like pictures and animations. Our emphasis is on the development of intuitive controls, placed in the hands of the artists, rather than on a physically-based simulation of the underlying processes. To this end, we focus on what we believe to be the most significant watercolor effects, and describe a pipeline where each of these effects can be controlled independently, intuitively and interactively, see Figure 12.

Our goal is the production of watercolor renderings either from images or 3d models, static or animated. In the case of animation rendering, temporal coherence of the rendered effects must be ensured to avoid unwanted flickering and other annoyances. We describe two methods to address this well-known problem that differ in the compromise they make between 2d and 3d.

This work has been published in NPAR '06 conference [16].

(a) (b) (c)

Figure 12. Various watercolor-like images obtained either from a 3d model (a,b) or from a photograph (c) in the same pipeline.

6.3.2. X-Toon: An Extended Toon Shader

Over the past decade, toon shading has proven popular in a variety of 3D renderers, video games, and animations. The idea is simple but effective: extend the lambertian shading model by using the computed illumination (a dot product between a light vector and the surface normal) to index into a 1D texture that describes how the final shading varies from dark to light regions. The designer controls the behavior of the shader by creating a 1D texture, typically composed of two or three regions of constant color, to mimic the flat regions of constant colors found in comics and traditional animation. Toon shading can be implemented efficiently via vertex and fragment programs on modern GPUs.

A limitation of toon shading is that it does not reflect the importance or desired level of detail (LOD) of a surface. Such LOD behavior plays an important role in traditional media, however. Often, some objects are considered more important (*e.g.*, characters vs. background) and thus are depicted with greater detail. In paintings and drawings, an effect known as aerial perspective makes objects in the background appear desaturated and less detailed than those in the foreground. And in scientific illustration, a technique similar to depth-of-field is used to focus on a region of a shape by decreasing contrast or opacity in less-important or out of focus parts of the surface.

Another limitation of ordinary toon shading is that it is view-independent, and so cannot represent plastic or metallic materials, for which view-dependent highlights are of primary importance. Similarly, it cannot support the view-dependent backlighting effects, often used in traditional comics and animation, in which a virtual back light illuminates the surface near the silhouette.

Finally, in conventional toon shading, every surface location is rendered with full accuracy, so that even small shape details are depicted by the shading (in at least some views). This can be desirable, but often designers working traditionally apply a degree of abstraction so that small shape details are omitted. A similar ability to depict an abstracted version of the shape is thus desirable in an automatic toon shader.

In this work we describe X-Toon, see figure 13, a toon shader that supports view-dependent effects through two extensions to conventional toon shading. The first incorporates a notion of tone detail, so that tone varies with depth or orientation relative to the camera. For this, we replace the conventional 1D texture used in toon shading with a 2D texture, where the second dimension corresponds to tone detail. We describe several ways to define the additional texture coordinate. Our second extension lets us vary the perceived shape detail of the shading. We achieve this by using a modified normal field defined by interpolating between normals of the original shape and normals of a highly abstracted shape. This approach has the advantage of abstracting the shading from a shape (while preserving silhouettes).

This work has been published in NPAR '06 conference [15] and is the result of the Eurodoc grant obtained by Pascal Barla for his stay in the University of Michigan.

Figure 13. Some example effects achieved by our extended toon shader (from left to right): continuous levels of detail, abstraction of near-silhouette regions (smoothing and opacity), backlighting and highlighting (plastic and metallic).

6.3.3. A perception-based criterion for the automatic selection of feature lines

Our ability to recognize objects from images relies on many visual cues, including colour, contrast, luminance, etc. It has been proven that edges are processed faster by our visual system than any other kind of information. That is the reason why line drawings, where strokes outline the objects features, allow an efficient and intuitive depiction of objects. This is attested by cognitive studies showing that line drawings are sufficient for the recognition of familiar objects.

There is a large variety of methods in computer graphics to compute feature lines from a 3D model. These methods allow the extraction of different types of lines, such as contours, borders, suggestive contours, creases, ridges and valleys. However, as feature lines are extracted based on geometric properties, there is no evidence that they actually convey relevant information, that is, information in coherence with what we perceive. Moreover, since different types of lines may convey complementary information, they have to be combined to depict the entire object s shape. To our knowledge, there is no combination scheme that ensures that the resulting drawing is not too dense. Unfortunately, no selection mechanism is provided to keep only the most relevant lines.

In this work we address the problem of producing a line drawing from a 3D model that correctly describes the geometry of the model. To this end, we use a psychovisual filter in order to evaluate the relevance of feature lines extracted from a 3D model, see Figure 14.

This work has been presented as a poster at NPAR06 [25] and is part of the MIRO project (see section 8.1.4) in collaboration with IPARLA (a project from INRIA Futurs).

6.3.4. Stroke pattern analysis and synthesis

A particularly important class of non-photorealistic renderings is that of stroke-based images. Various styles such as etchings, pen-and-ink and oil painting renderings can be thought of as stroke-based styles. The

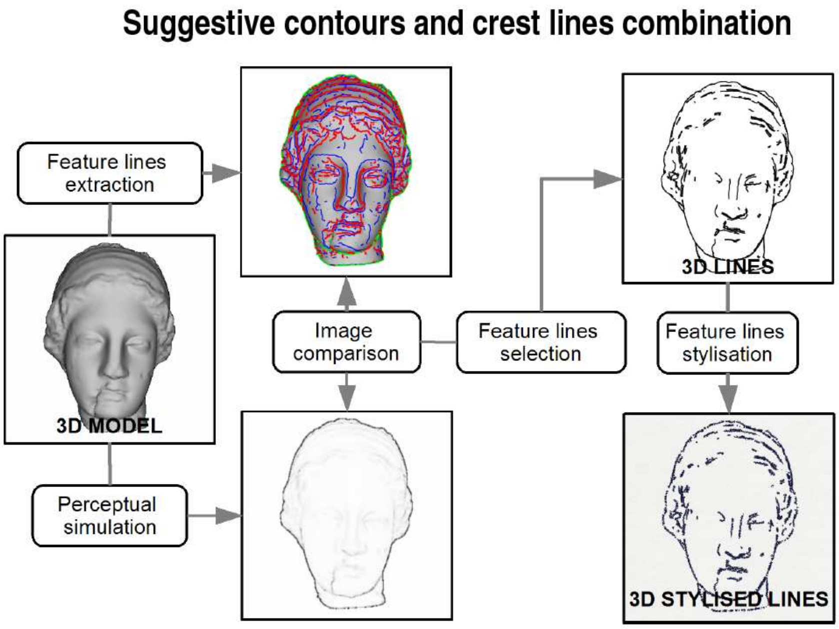


Figure 14. The selection of feature lines.

rendered strokes can be either used to fill in 2D regions, as in painterly rendering, or to annotate 1D paths, like with some hatching patterns; in both cases, the generation of appropriate stroke arrangements for these styles remains a difficult or tedious process to date. Since the individual style of each artist has to be conserved but is not easy to translate in an algorithmic representation, we can not simply rely on procedural methods to generate stroke patterns. Finding a compromise between automation and expressiveness is then crucial for such renderings to be used by artists.

Synthesis by example appears to be the best way to address this question. However, pixel-based texture synthesis is not well suited to stroke patterns, in part because each element of a stroke pattern is individually perceptible, in contrast to pixels. Organized stroke clusters such as those found in hatchings are difcult to extract and reproduce at the pixel level. Moreover, some variation in the reproduced pattern is desirable to avoid too much regularity, and it would be difcult to achieve such variation with pixel-based texture synthesis.

We therefore propose to use a vector-based description of an input stroke pattern supplied by the user. This allows for greater expressiveness and higher-level analysis than would be afforded by a per-pixel approach. The stroke geometry is represented explicitly as connected vertices with attributes such as width and color.

We have worked on two methods to adress this question. The first one (published as a technical report [24]) bears similarities to parameteric methods on texture synthesis in that it performs a statistical analysis of properties of the input pattern (such as stroke positions, lengths, and orientations). However such methods are hard to extend to general patterns because the parameters depend heavily on the style and structure of the pattern. We thus have worked on a more general method (See Figure 15) that targets any kind of stroke patterns (stippling, hatching, brush strokes, small figures) with a quasi-uniform distribution of positions in 1D and 2D (along a path or inside a region). The strokes attributes can vary in non-uniform ways and the only parameter required from the user is the scale of the meaningful elements of the pattern. Then, in a manner analogous to texture synthesis techniques, we organise our method in two stages. An analysis stage where we identify the relevant elements in terms of stroke patterns and their distribution, and a synthesis stage where these elements are placed in the image so as to reproduce an appearance similar to the reference pattern. It has been published in Computer Graphics Forum [4] and is the result of the Eurodoc grant obtained by Pascal Barla for his stay in the university of Michigan.

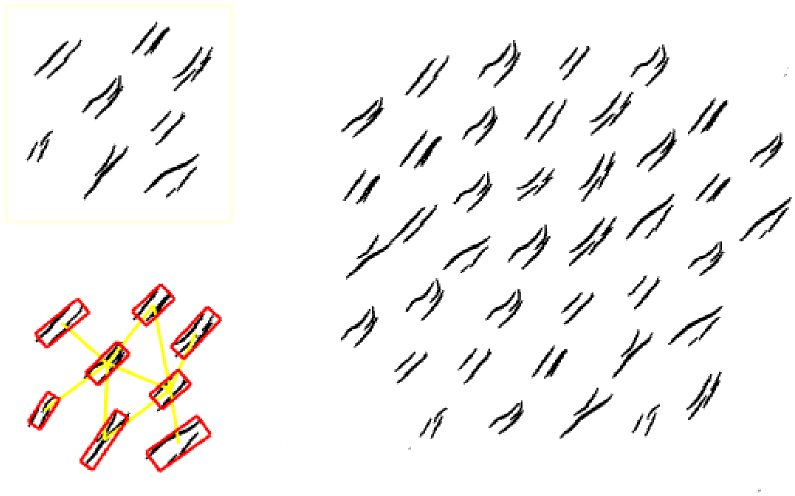


Figure 15. Our method for pattern synthesis takes as input a reference vectorized stroke pattern, then analyses it to extract relevant stroke pattern elements and properties in order to synthesize a similar pattern.

6.3.5. A dynamic drawing algorithm for interactive painterly rendering

Painterly rendering is a technique that takes inspiration from traditional paintings, usually focusing on effects similar to those achieved with oil or acrylic paint, where the individual brush strokes are more or less perceived individually. The main idea is to render a scene projected on the image plane by a set of 2D vector paint strokes holding style attributes (color, texture, etc). This representation has the effect of abstracting the rendering by using primitives larger than pixels, and emphasizing the the 2D nature of the image through 2D paint strokes.

In the general case, paint strokes simultaneously represent information about objects in the scene (such as shape or reflective properties of a surface from the current point of view) while following a stroke style provided by the user (straight or curved brush strokes, thick or thin outline, etc). During the animation they also follow the 2D or 3D motion of some scene elements. The main issues in painterly rendering originate from these conflicting goals. **Temporal coherence** of the strokes motion is of primary interest: it comes from the desire to link the motion of a 2D primitive (a stroke) to that of a 3D primitive (e.g. a surface). Another important aspect is the **density** of strokes: when zooming in or out from an object, the number of strokes used to represent it must increase or decrease in order to maintain a uniform density in the picture plane while keeping a constant thickness in image space. Finally, an ideal painterly renderer would let the user fully specify the strokes **style** in a way that is independent from the depicted scene, but at the same time should ensure that some properties of the scene are well-represented, such as object silhouettes or lighting.

We present an object-space, particle-based system that extends the pioneering work of Meier [38]. Our main contribution is a fully view- and lighting-dependent behavior that explicitly performs a trade-off between a user-specified stroke style and the faithful representation of the depicted scene. This way, our system offers a broader expressiveness by removing the constraints usually found in previous approaches, while still ensuring **temporal coherence**.

This work has been presented as a poster at NPAR06 [26] and a sketch at SIGGRAPH'06 [22].

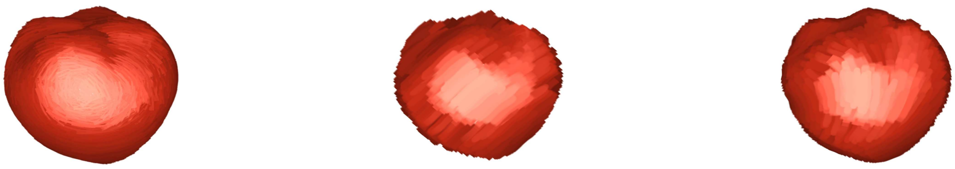


Figure 16. Three different painterly styles produced by our method at interactive rates. Left: long strokes are drawn along silhouettes using surface normals. Middle: strokes have a common global orientation set by the user. Right: Surface principal curvature is used to orient thick strokes. Note that illumination features such as shading and highlights are correctly represented independently of the user's stylistic decisions.

6.3.6. Automated Style Analysis

Pierre-Edouard Landes has started his PhD in late 2006. His work aims at understanding the mecanisms which could lead to an automated extraction of style in expressive renderings. During his DEA, he successfuly applied *style analogies* – following the work of A.Hertzmann [35] – for automatically relating the geometric features of a 3D model to the parameters of a NPR style used to render it.

In the beginning of his PhD, P.E.Landes works on the automated extraction of frequent objects in an image. Such objects may furthermore be partially masked by each others, or deformed in an inpredictable way. The work aims at automatically recovering the information that such an image was generated by pasting a single model possibly modified (deformed, colors modified, etc) as well as the range of parameters that represent these modifications.

Among the possible applications to this work is the "intelligent" analysis and synthesis of near-regular textures. But more importantly, such a system could be applied to the extraction of style in expressive drawings, based on the assumption that frequent patterns belong to the set of drawing primitives, rather than to the objects which are depicted.

6.4. Virtual Reality

Keywords: *3D interaction*, *augmented reality*, *mediated reality*, *mixed reality*.

Participants: Jean-Marc Hasenfratz, Jean-dominique Gascuel, Marc Lapierre, Alexandrina Orzan.

6.4.1. CYBER II: Omnidirectional texturing

To make the model in the CYBER II framework (see section 3.5.1) more realistic, we map the images captured from the video streams onto the 3D shape. Since we have a set of cameras, we have more then one view for the same patch of the 3D model. In addition, the geometry of the model is limited to about 5000 triangles, not sufficient to have a good mesh representation, but necessary if we want to obtain it in real time.

In this context, we proposes to identify the problems of multi-view texturing for approaches where the 3D model is given; model-free and to offer solutions for a number of them. We successfully treat visibility issues, identify "crisk zones", correct projection displacement errors and fill in small untextured areas. Our algorithm works in real time, thus permitting an interactive viewing of the augmented scene. The pipline of the treatment is proposed in Figure 17. First result are published in [21].

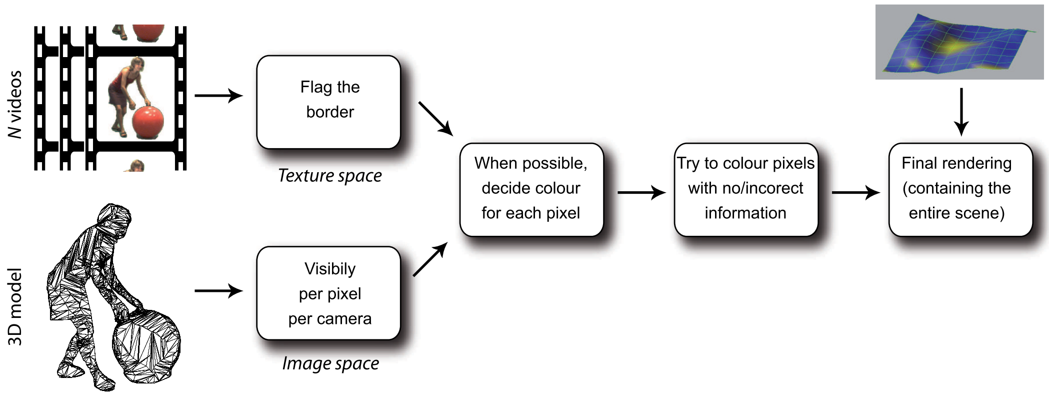


Figure 17. Pipeline for multi-view texturing.

6.4.2. Virtual Reality and Rehabilitation

Since 2001, a collaboration was established between O. Martin (MCU UJF/UFRAPS/SPM Grenoble), C. Prablanc (DR INSERM U534 Lyon) and ARTIS. This collaboration had two symetric sides: to assess the usability of virtual reality environment for neuro-sciences experiments on the perception-action loop; and to find measures of comfort and immersion of a virtual setup. Last year, we have been joined by Paul Pavan (Kinesitherapist at the Grenoble University Hospital). He routinely uses a projection device (that generate moving light dots) to stress balance of patients, in order to do rehabilitation eg. after brain traumas.

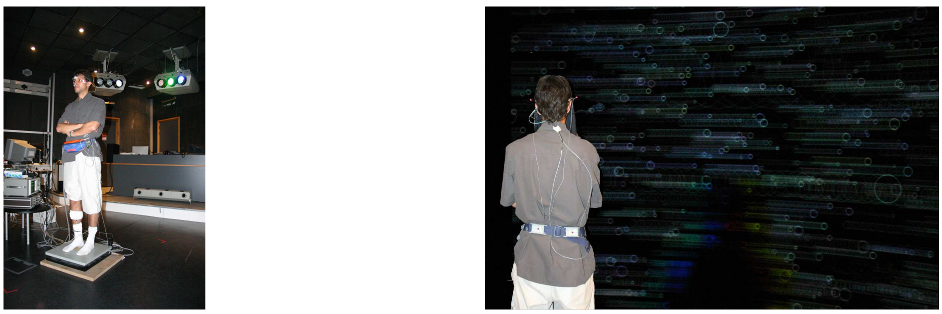


Figure 18. The new simpler experimental environment. (left) The instrumented patient, with devices to record 3D positions, and muscular activations. (right) The patient reacting at the computer generated motion field.

We provided a flexible stimulation environment suitable to reproduce qualibrated motion field sequences, using a simple VR setup, a laptop, a video projector, and a few input devices. The aim is to record balance control and adaptation when shown various types and directions of motion fields.

A test experiment took place in june 2006 (see figure 18. A small sample of well being people (10 “naive” students from another lab) where used in a first scenario. We are still exploting the numberous records, but we are already confident that the setup was indeed able to induce standard balance control mechanisms a user will have in real life world.

6.5. Geometric analysis

Participants: Samuel Hornus, Aurelien Martinet, Cyril Soler, Nicolas Holzschuch, Francois sillion, Elmar Eisemann, Xavier Décoret.

6.5.1. Semantic analysis of non coherent geometry

Aurélien Martinet started his PhD in 2003, under the supervision of Cyril Soler and Nicolas Holzschuch, working on the automatic extraction of semantic information from non coherent geometry. This work aims at answering a recurrent need in computer graphics: most researchers work with 3D scene data into which they need high level information such as which groups of polygons form connex shapes, human regognisable objects, have symetries, or even which groups of polygons look like each other (also known as *instancing information*). Unfortunately such high level information is most of the time not present in 3D geometry files, either because it was lost during format conversions, or because it was not defined the same way by the designer of the model.

The question to be solved is thus how to automatically retrieve some high level (also named *semantic*) information from a *polygon soup*, *i.e* a list of polygons without any information about how these polygons are related to each other. During the passed year, Aurelien has focused on developing a new technique for automaticaly extracting instantiation information in a scene, on the basis of the work he previously performed for extracting symmetries of objects [8]. Figure 19 shows an example of an instancing graph automatically obtained using this method: this structure is a Directed Acylic Graph where each node is associated to a "generic object" which is instantiated in the scene, and each edge represents the geometric transformation of each instance.

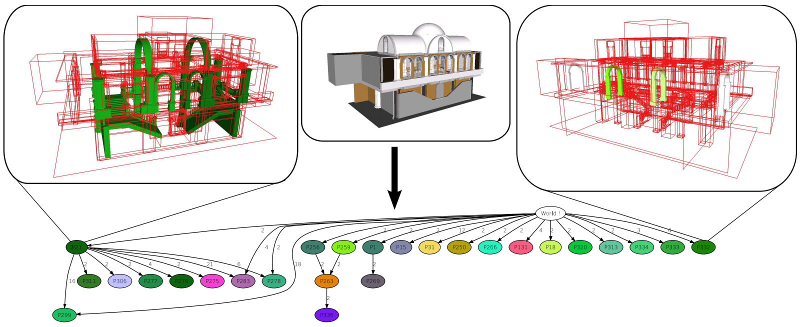


Figure 19. From the input model (top center) , we compute a hierarchy of instances which give a "structure" to the model. This structure is a Directed Acylic Graph where each node is associated to a "generic object" which is instantiated in the scene, and each edge represents the geometric transformation of each instance. For clarity, we replace n multiple edges between two nodes with a single edge labeled n. On each side of the Figure, we present two examples of instances detected by our method. Our basic assumption is that the input model is completely unstructured and is therefore given as a polygon soup.

6.5.2. On Exact Error Bounds for View-Dependent Simplification

In view-dependent simplification, an object is simplified so that the difference between original and simplified versions *as seen from a given viewcelll* is bounded by a given error. The error is the maximum reprojection error, that is the distance between the projection of a point in image, and the projection of its counterpart in the simplified version.

To guarantee an error bound, one must know how much a point can be moved from its original position to satisfy the reprojection error bound. This defines the *validity region* of the point. Surprisingly, finding this region is a very difficult geometric problem. Elmar Eisemann worked on it during his master and found very important results. For example, the error bound cannot be checked only at the vertices of the mesh. Also, the maximum reprojection error is not necessarily observed at one of the corner of the viewcell. Finally, he showed how to compute exactly the validity region for the 2D case and opened the way to an extension to the 3D case. The proof is elegant and very inovative. It provides the first exact bound on view-dependent simplification error. In contrast, previously published bounds were often only approximate (though sufficient for the considered application). The results have been accepted as a journal paper [6].

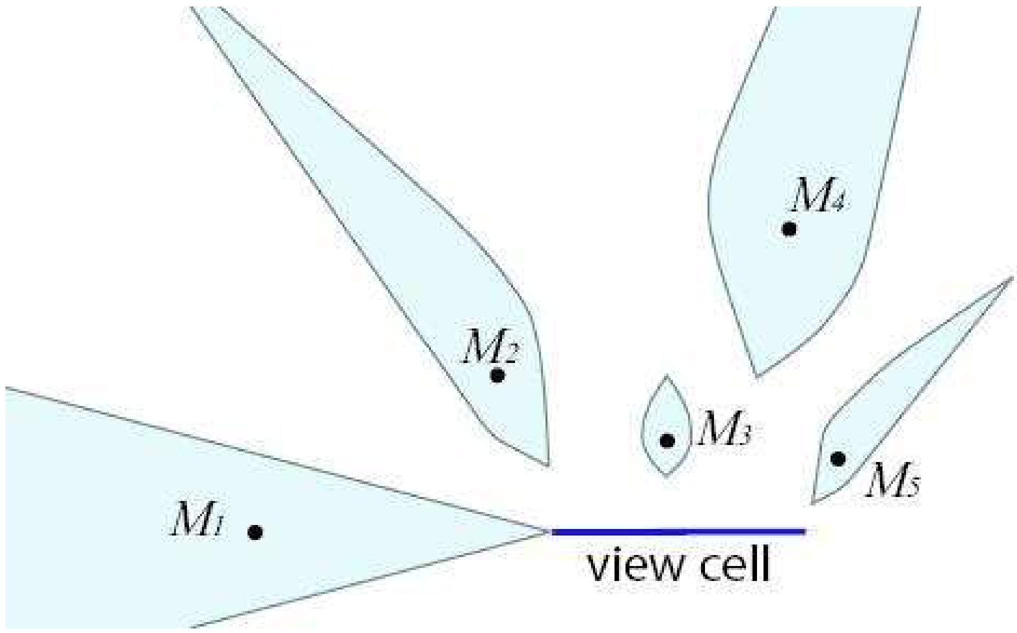


Figure 20. Validity regions of points that bound the reprojection error as seen from a line viewcell. We are able to describe exactly these regions.

7. Contracts and Grants with Industry

7.1. Noveltis

Participants: Cyril Soler [contact], Francois Sillion.

Noveltis is a company established in Toulouse (France) and its main activity is to perform studies of applicability and to provide usable solutions to clients in various scientific application domains such as atmospheric physics and chemistry, oceanography, land surfaces and astrophysics. The technology itself is obtained through consolidation and promotion of scientific work as a tool for analysing and managing environmental problems. Noveltis is developing a partnership with INRIA for using the PlantRad software developed by ARTIS into a framework for simulating embeded sensors on satellites. In this context PlantRad serves for the computation of the reflectance of mixed forest and urban regions of the earth surface. This collaborative work has led to a publication with the Radiation Transfer Model Intercomparison work team [12].

7.2. CIFRE with Eden Games

Participants: Nicolas Holzschuch [contact], Lionel Atty, Francois 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 second year, is working on rendering photorealistic effects, such as soft shadows, in real-time.

7.3. Graphanim

Participants: Joelle Thollot [contact], Adrien Bousseau, Francois sillion.

An industrial contract for a one year collaboration has begun in March 2006 with a movie studio in Paris name Studio Broceliande. The goal is to produce a Maya plugin that renders an animation in a watercolor style based on one of our publication [16].

8. Other Grants and Activities

8.1. National grants

8.1.1. Grants supporting the CYBER research project

The CYBER-I project was supported by the "ACI Jeunes Chercheurs" of the Department of the Research (2001-2003). The continuation of this project is CYBER-II which is supported by the "Massive Data" program of the Ministry of the Research (2003-2006). In this second step, we will improve the realism by augmenting the number of cameras (approximatively 20), by using a grid of PC and by visualizing the augmented scenes at very high resolutions, using a multi-projector setup.

8.1.2. Research Ministry grant: SHOW

SHOW is a collaborative research action funded under the French Ministry of Research "Massive Data" program, a program for projects for processing, managing and visualizing very large datasets.

SHOW joins together four INRIA projects: Reves of INRIA Sophia, ISA of LORIA and Iparla of UR-Futurs (in Bordeaux). We are working on very large datasets, and we extract their structure for edition and interactive display.

The ARTIS project is working on very large datasets that represent an architectural model, including walls, windows, doors, furnitures, and small objects. The model is unstructured, as often happens in industrial applications, usually as the consequence of applying an automatic translator on the 3D data.

We are working on the automatic generation of a spatial and semantic structure out of this unstructured dataset, using geometrical tools and techniques from Computer Vision. The goal is to separate and identify in the database the walls, furniture and other objects. The other research projects will be using the generated structure for simulation, parameterization and visualization of the architectural dataset.

8.1.3. Region Rhône-Alpes investigation grant: DEREVE

The Region Rhone-Alpes is funding the Dereve research project. The project has been going on for three years in its first phase (Dereve, 1999-2002) and is now in its second phase (Dereve II, 2003-2006). The Dereve research project is grouping together the ARTIS and EVASION research teams of the GRAVIR research laboratory, the LIRIS research laboratory in Lyon and the ICA research laboratory in Grenoble. The goals of the Dereve project are to render large and animated virtual environments in real time, using either photorealistic rendering or non-photorealistic rendering.

In the Dereve project, we are also working in collaboration with the ARIA research laboratory of the Lyon school of Architecture, who is producing a 3D model of the "Ideal City" by the famous Lyon architect, Tony Garnier. Since the city was never built, the architects are seeing fit to have a non-photorealistic rendering of the city, to underline its virtual status.

8.1.4. INRIA investigation grant: MIRO

ARTIS is participating to the ARC MIRO in collaboration with IPARLA (INRIA Futurs) and associate partners: Roberto Scopigno (Istituto CNUCE, Pisa, Italia), Robert Vergnieux (AUSONIA, Institut de recherche sur l'antiquité et le moyen Age, Bordeaux), Bernard N'kaoua (Cognitive Science Group, Bordeaux 2) and Digisens SA (Annecy, France).

In this project, we are interested in using NPR for the interactive and legible rendering of complex 3D scenes. The complexity is related to the massive amount of data and to the intrinsic nature of information (images, texts, illustrations...). Many examples in scientific visualization prove that photorealism does not always offer meaningful images. For example in medical books, the representation of organs is more frequently based on sketches and annotations than on photographs.

State of the art rendering techniques do not offer suited tools for perceptually effective, legible rendering of complex data. Researchers in the ARTIS and IPARLA projects are working on these topics, in the context of archeology, museography, medical simulation, all applications that require specialized visualizations. To address the legibility question we rely (i) on the skills and experience of the IPARLA and ARTIS teams; (ii) on the knowledge of specific users: archeologists, museum curators, industrial users at Digisens (the startup specialized in CTscan reconstruction and dental chirurgy); (iii) on the skills of the Bordeaux lab of cognitive psychology who helps us to define the type of validation needed for our methods.

8.1.5. INRIA investigation grant: GEOREP

ARTIS is participating to the ARC GEOREP. Following his work on heightfield rendering, Lionel Baboud is working with Bruno Levy to replace complex geometric objects with small geometric patches encoded as heightfield textures.

8.2. Association with MIT CSAIL graphics group

INRIA's 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 in 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 and 2007. This association, now in its fourth 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 [27], [29], [31], [30], [32], [28] are co-signed by researchers from the two groups).

The activity of the associate team in 2006 focused on the following two items:

- A visit of Soonmin Bae in June 2006, during which we discussed the possibilities of using differently focused images to recreate depth of field effects for digital photography.
- the development of our 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.

8.3. Exploradoc grants

The Region Rhône-Alpes has established a grant program to help PhD students in starting actual international cooperation during their PhD years. The following actions have been supported by the program:

8.3.1. Chalmers University of Technology, Göteborg, Sweden

David Roger has been visiting Ulf Assarsson at the Chalmers University of Technology, at Göteborg, Sweden, for six months in 2006. This visit was supported by a grant from the Exploradoc program of the Région Rhône-Alpes. During this collaboration, David Roger had worked on GPU algorithms, first a packing algorithm for removing zero entries in an array of number, then a ray-tracing algorithm based on a hierarchy on the rays instead of the usual hierarchy on the scene.

8.3.2. Harvard University, Cambrige, MA, USA

Emmanuel Turquin has been visiting Steven Gortler at the Computer Graphics team of Harvard University (Cambridge MA, USA). This visit was supported by a grant from the Exploradoc program of the Région Rhône-Alpes. During this visit, Emmanuel Turquin worked in collaboration with Pr. Steven Gortler. They explored different topics, notably some geometric considerations to improve a sketch-based cloth modelling canvas, a method to automate icon placement on a desktop in order to keep both the efficiency and aesthetics of the desktop metaphor, an heuristic model of dynamic crowd behaviour based on centroidal Voronoi diagrams, and last but not least, a point-based approach to the (pre-)computation of light transport, which could be used to obtain real-time global illumination on geometrically complex scenes under dynamic local lighting.

The method for sketch-based clothed modelling canvas has been accepted for publication in *IEEE Computer Graphics & Applications* [11].

8.3.3. University of Illinois, Urbana-Champaign, IL, USA

Elmar Eisemann has been working with John C. Hart in the Computer Graphics Group of the University of Illinois (Urbana-Champaign, IL, USA). A grant from the Exploradoc program of the Région Rhône-Alpes made the stay possible. During the visit Elmar Eisemann worked together with Prof. Hart and Matei Stroila on clipart rendering of volume data.

9. Dissemination

9.1. 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 7.2). 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 is a member of the scientific committee of the “Pôle de compétitivité”.

9.2. 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[7]. 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, 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 “fete de la science” (scientific vulgarization event), and is often consulted for its scientific expertise.

[7] http://artis.imag.fr/Publications

9.3. Code on the Web

9.3.1. 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 [32], [30]. This software is distributed under the terms of the GPL License.

9.4. Other activities

- François Sillion is:
  - Member of the program committee of Siggraph '06, EGSR '07, I3D '07, Pacific Graphics and NPAR '06.
  - Member of the editorial committee of ACM Transactions of Graphics and Computer Graphics Forum,
  - Member of the administrative board of EG,
  - "EG Fellow" since 2005,
  - President of the projects committee of INRIA Rhône-Alpes,
  - Member of the commission of evaluation of INRIA.
- Joëlle Thollot is:
  - Member of the program committee of NPAR '06,
  - Member of the "Commission de Spécialistes" of INPG,
  - Member of the "Conseil d'Administration" of ENSIMAG,
  - Member of the "Comité d'UR" of INRIA Rhône-Alpes.
- Nicolas Holzschuch is both the local organiser of EGSR 2007 (to be held in Grenoble) and a member of the program committee of EGSR 2007.
- Xavier Décoret is:
  - Member of the program committee of I3D'07, SMI'07,
  - Member of the "Comité d'UR" of INRIA Rhône-Alpes.

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