INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team artis

Acquisition, Representation and Transformations for Image Synthesis

Rhône-Alpes

THEME COG

Activity Report

2005

Table of contents

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).

Head of project-team
François Sillion [DR1, INRIA]

Administrative assistant
Patricia Mathieu [CNRS (GRAVIR)]
Ornella Mazzéo [UJF (GRAVIR)]

Research scientist
Jean-Dominique Gascuel [CR1, CNRS]
Nicolas Holzschuch [CR1, INRIA]
Cyril Soler [CR1, INRIA]
Gilles Debunne [CR2, CNRS (on leave since July 1, 2005)]
Xavier Décoret [CR2, INRIA]

University faculty
Joëlle Thollot [Associate Professor, INPG (detached to INRIA since September 1, 2005)]
Jean-Marc Hasenfratz [Associate Professor, Université Pierre Mendès-France]

Project technical staff
Marc Lapierre [funded by ministry of research ACI]
Jean-Christophe Roche [funded by an EU IST project (until March 31, 2005)]

Post-doctoral fellow
Ulf Assarsson [Ministry of research / INRIA (until September 13, 2005)]
Héctor Briceño [Université Joseph Fourier (until August 31, 2005)]
Matthew Kaplan [ARC MIRO (since August 31, 2005)]

Ph. D. student
Stéphane Grabli [INRIA, until March, 2005]
Samuel Hornus [AMN]
Aurélien Martinet [ACI MD SHOW]
Pascal Barla [MESR]
Elmar Eisemann [AMN]
David Roger [AMN]
Emmanuel Turquin [MESR]
Lionel Atty [CIFRE]
Lionel Baboud [MESR]
Hedlena Bezzerra [Marie Curie host VISITOR]
Alexandrina Ozran [Marie Curie host VISITOR]
David Vanderhaeghe [MESR]

Visiting researcher
Charles Hansen [University of Utah, until August, 2005]

Associated researcher
Frédo Durand [MIT]
Denis Haumont [Université libre de Bruxelles]

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 include:

- 3D image synthesis;
- illustration (animation, technical illustration);
- virtual and augmented reality;
- virtual archeology;
- radiative transfer simulation.

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, Jean-Christophe Roche, Emmanuel Turquin, Samuel Hornus, David Roger, Ulf Assarsson.

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 rendering 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; and 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, Jean-Dominique Gascuel, Joëlle Thollot, Cyril Soler, David Vanderhaeghe, Matt Kaplan, Hedlena Bezerra, Stéphane Grabli, Pascal Barla.

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. It is necessary to define relevance both qualitatively and quantitatively. , Relevance is the relative importance of various scene elements, or their treatment, for the desired result. 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, Gilles Debunne, Xavier Décoret, Hector Briceño, Yannick Le Goc, Samuel Hornus, Elmar Eisemann, Aurélien Martinet.

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, Marc Lapierre, Alexandrina Orzan, Charles Hansen.

mixed reality set of techniques involving the addition of real elements to a virtual world, or virtual elements to the real world

The evolution of technology, with high-quality 3D graphics becoming available on consumer-grade computers, while image and video acquisition has become fully digital, has made the convergence of real and synthetic imagery a real possibility. Applications of mixed realities are blooming and we are interested in providing appropriate tools for these new uses of graphics. One fundamental issue in mixing real and synthetic imagery lies in the proper combination of the two image sources. 3D visibility is, of course, a difficulty, requiring some form of 3D reconstruction from real imagery. However our focus is more 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.

The notion of relevance-guided rendering, as described above, is also inspiring us to investigate possible constraints placed on the rendering process by virtual reality applications. In this spirit we are studying the effects of virtual reality immersion for performing a given task.

On the other side of the virtual/real continuum, augmented reality can provide the possibility to manipulate 3D virtual objects in the real world (while keeping easy eye contact and visibility of real artefacts, as opposed to what happpens with virtual reality). This introduces new issues. Registering (visual and spatially) the two worlds remains a major difficulty: efficient calibration algorithms are required. Providing natural, simple and intuitive new interaction metaphors requires user studies and new explorating solutions (coupled with dedicated input and output devices). Also, we must define a formal frame for the possible interactions with the real world (*e.g.* modify the appearance of the real world).

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).

Our purpose is:

- an integration of the actors as realistic as possible.
- 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 (see Figure 1).

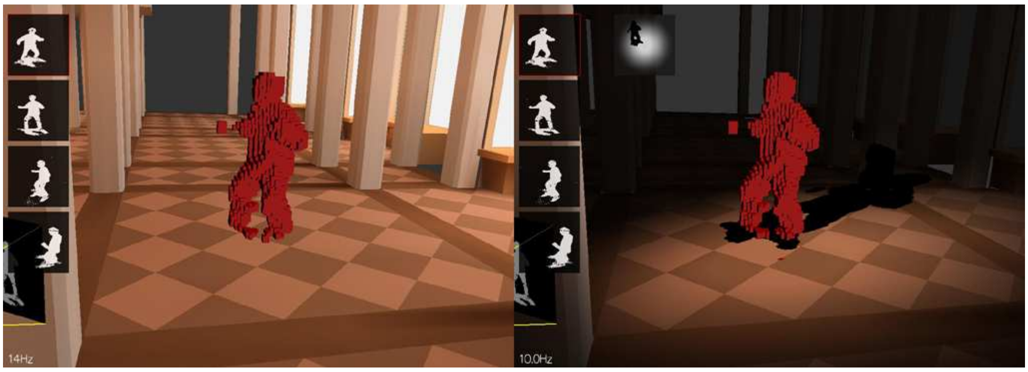


Figure 1. Shadow due to a virtual light. Left: the actor seems to be "flying" above the floor. Right: shadows remove this impression

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 [37] and a more interactive version has been published in "Virtual Environments" [38].

[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.

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 [40]).

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, LOD, 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 rendering 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. Collaborative work

Collaborative Work is an essential activity in the worflow of many companies to coordinate and share information among employees. Groupware have largely emerged during these last years for colocated or distant meeting (*e.g.* Microsoft NetMeeting). In this context, few results have been etablished for the support of colocated activities for 3D tasks (manipulation and visualization of 3D content). Solutions provided by virtual reality setups (CAVE, Responsive Workbench) seem too limited in terms of intuitive interaction metaphors, good working conditions and collaborative support.

In the continuity of previous years research, ARTIS proposed a new vision-based augmented reality, dedicated to tabletop meeting. Augmented reality delivers a large support for keeping natural metaphors of communication (verbal or gesture), and support for simple and intuitive 3D interaction metaphors. This approach has applications in a large variety of domains related to collaborative work: Architecture, Scientific Visualization, Game, Design etc.

4.5. 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 amongst which we foresee:

- Virtual studio: The speaker of a TV show can be included and interact within a virtual world in real-time. As there is no apparatus, even spectators can come at any moment to play or navigate within the virtual set.
- Teaching/Training: this platform may also be used for teaching or training application. A teacher could manipulate in coordination with students for example molecules or any virtual object, interact with it and see in real-time its behavior. For training applications, it can be used for example to train people with a simulation of intervention in nuclear plants or other sites where real conditions are critical.
- Virtual prototyping: in industry it is common to have one model on which engineers from different fields want to collaborate. With this platform it is possible for them to share and view the same model, for example a car (1:1 scale), so that they can manipulate and expose to others any specific part or behavior.
- Multi-sites: Its possible to imagine communicating platforms like this: it would allow persons from different sites to navigate in the same virtual world, manipulate objects or even interact with each other.
- Virtual Archaeology: for archaeologist it is hard to recreate and imagine how was a ancient site. With this platform you can navigate within a virtual world, and have a realistic idea of the specific lighting of a monument (as you cast shadows on the virtual world).

- Virtual Homes: Virtual worlds can be ancient sites, but also future places: it is now possible to make a customer visit his new kitchen or her home before it is build. He can interact and manipulate any furniture and estimate this configuration in real-time.

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. X3DToolKit: a library for reading/displaying X3D files

Participants: Gilles Debunne [contact], Xavier Décoret, Yannick Le Goc.

One of the annoying problems in Computer Graphics is 3D file format manipulation. There are many proprietary file formats, making conversion or even loading a tedious task. In this context, X3D, a new open file format developed by the W3C consortium, based on an XML representation and hence extensible, appears as a promising future standard.

Another common need is for a set of tools that process 3D models and meshes in order to make them suitable for the application (removal of degeneracies, simplification, API to access the topological structure...).

Yannick Le Goc was hired by INRIA as a junior engineer to develop the X3DToolKit library, which addresses these requirements by providing a complete loading mechanism for X3D data, as well as a scene graph representation and clear processing mechanisms. X3DToolKit has become a standard software component in our group, facilitating the adoption of X3D as a standard data format. X3D is distributed under the LGPL licence and is freely available for download[2].

Yannick finished his contract in September 2004 and released a stable final version. Future developments are open to the community and a savannah project[3] will be created for that.

5.3. 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[4].

5.4. 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.

[2] http://artis.imag.fr/Software/X3D
[3] http://savannah.gnu.org
[4] http://artis.imag.fr/Software/QGLViewer/

5.5. High Quality Renderer

Participants: Cyril Soler [contact], Jean-Christophe Roche, 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.

5.6. 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 at http://www-imagis.imag.fr/mobinet/index.en.html 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 [42] in 2004.

5.7. Basilic : an Automated Bibliography Server

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[5].

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[6]

5.8. XdkBibTeX : parsing bibtex files made easy

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[7]

6. New Results

6.1. Lighting and rendering

Participants: François Sillion, Cyril Soler, Nicolas Holzschuch, Jean-Marc Hasenfratz, Lionel Atty, Charles Hansen, Samuel Hornus, Jean-Christophe Roche.

---

[5] See for instance http://artis.imag.fr/Publications
[6] http://artis.imag.fr/Software/Basilic
[7] http://artis.imag.fr/Membres/Xavier.Decoret/resources/xdkbibtex/

6.1.1. Lighting simulation in complex environments

We have developed a technique for computing solutions to the problem of light equilibrium in complex scenes that include plants. Our technique is based on hierarchical radiosity with clustering and instantiation. While this technique may be applied to any kind of scene, instantiation benefits highly from the multi-level approximate self-similarity of plants. Self similarity saves memory and thus the program in able to treat very large scenes.

In collaboration with *Noveltis*, Toulouse, our software called *PlantRad* now takes place in a large pipeline for simulating embedded remote sensing sensors on satellites. By pre-computing the reflectance of a soil covered by a given kind of vegetation, and comparing the results to those measured by the sensor (See Fig. 2), it is indeed possible to infer what is remotely seen by the sensor. These results have led to a publication [39].

This work has now reached the state of validation, which is performed toward standard results provided by the RAMI project (see Fig. 3). Despite the high difficulty specific to the RAMI test cases, very encouraging results have been produced by the PlantRad software while computing reflectance functions of the proposed synthesized environments.

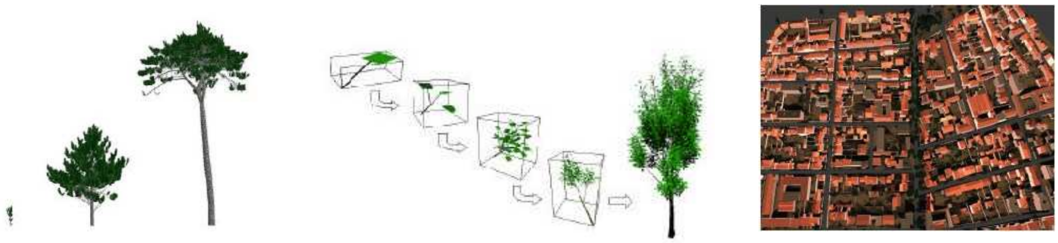


Figure 2. Lighting simulation in complex environments. Left: very complex models of trees are accounted for by the software using clustering and instancing techniques (middle) so as to obtain global illumination solution on very large scenes such as this entire region inside the town of 'Toulouse' (right).

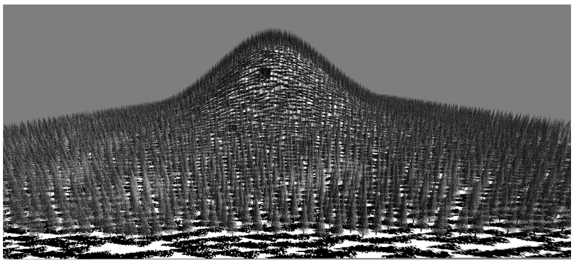


Figure 3. Validation of the PlantRad software on a virtual scene of pine trees featuring more than 60M polygons. Performing radiosity calculations on such a scene is made possible by the instancing strategy implemented into the software.

6.1.2. Hard shadows

We have developed a simple yet novel way to implement the rendering of hard shadows using the stencil shadows technique [31] (as used in the video-game Doom III). The basic technique has been well kown for more than ten years, but we express it in a slightly different way, that affords the use of advanced rasterizing

Figure 4. Our new method of rendering hard-shadows affords its applications to large meshes thanks to the use of vertex arrays and/or triangles strips.

methods of modern graphics hardware (triangle strips and vertex arrays, for optimized data transfers to the graphics card, see Fig. 4). This is joint work of Samuel Hornus, Jared Hoberock (UIUC), Sylvain Lefebvre (INRIA/EVASION) and John Hart (UIUC). This work has been published in the proceedings of the 2005 Symposium on Interactive 3D Graphics and Games [16].

6.1.3. A Frequency Analysis of Light Transport

We have developped a signal-processing framework for light transport. We have studied the frequency content of radiance and how it is altered by phenomena such as shading, occlusion, and transport (see Figure 5). This work extends previous work that considered either spatial or angular dimensions, and it offers a comprehensive treatment of both space and angle.

We have shown that occlusion, a multiplication in the primal domain, amounts in the Fourier domain to a convolution by the spectrum of the blocker. Propagation corresponds to a shear in the space-angle frequency domain, while reflection on curved objects performs a different shear along the angular frequency axis. As shown by previous work, reflection is a convolution in the primal and therefore a multiplication in the Fourier domain. Our work has shown how the spatial components of lighting are affected by this angular convolution.

Our framework predicts the characteristics of interactions such as caustics and the disappearance of the shadows of small features (see Figure 6). Predictions on the frequency content can then be used to control sampling rates for rendering. Other potential applications include precomputed radiance transfer and inverse rendering. This work was published at Siggraph 2005 [4].

6.1.4. Soft Shadows for Ray Tracing

We have developped a new, fast algorithm for rendering physically-based soft shadows in ray tracing-based renderers. Our method replaces the hundreds of shadow rays commonly used in stochastic ray tracers with a single shadow ray and a local reconstruction of the visibility function. Our algorithm produces exactly the same image as the classical soft-shadow method for ray-tracing, tracing hundreds of rays, while executing one to two orders of magnitude faster in the test scenes used.

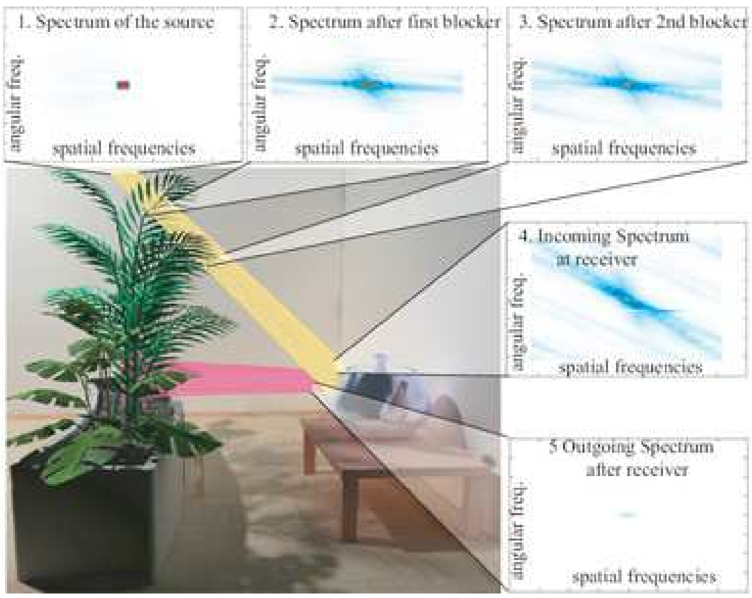
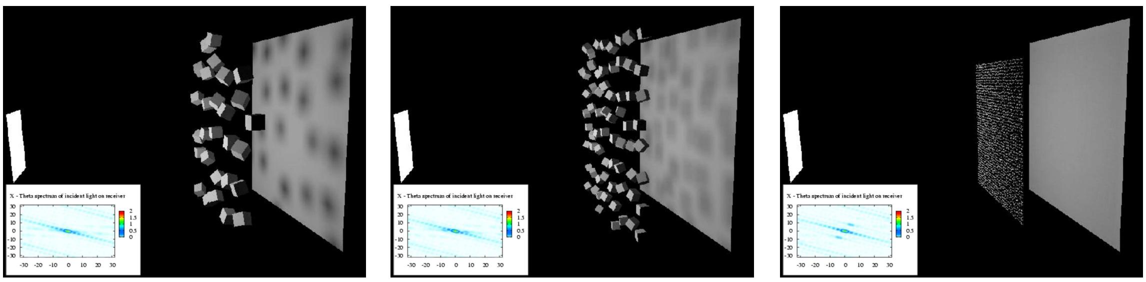


Figure 5. Space-angle frequency spectra of the radiance function measured in a 3D scene. We focus on the neighborhood of a ray path, and measure the spectrum of a 4D light field at different steps, which we summarize as 2D plots that include only the radial components of the spatial and angular dimensions. Notice how the blockers result in higher spatial frequency and how transport in free space transfers these spatial frequencies to the angular domain. Aliasing is present in the visualized spectra due to the resolution challenge of manipulating 4D light fields.

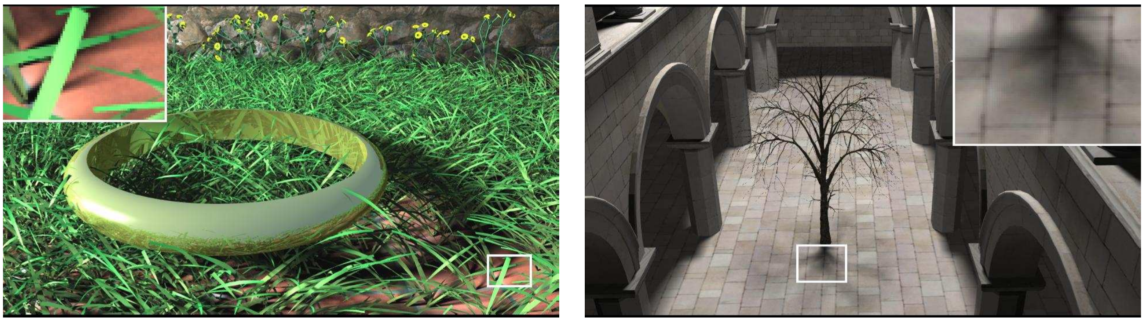


(a) Large occluders: low frequency content on the receiver

(b) Smaller occluders: higher frequency content on the receiver

(c) Very small occluders: only low frequency content remains

Figure 6. One interesting application of our framework: increasing the frequency content of the occluders (reducing the size of the occluders) results, first, in an increase of the frequency content on the receiver (a to b), but if the frequency content of the occluders increases again, high frequencies disappear on the receiver (c). Our framework explains and predicts this well-known phenomenon.



(a) (b)

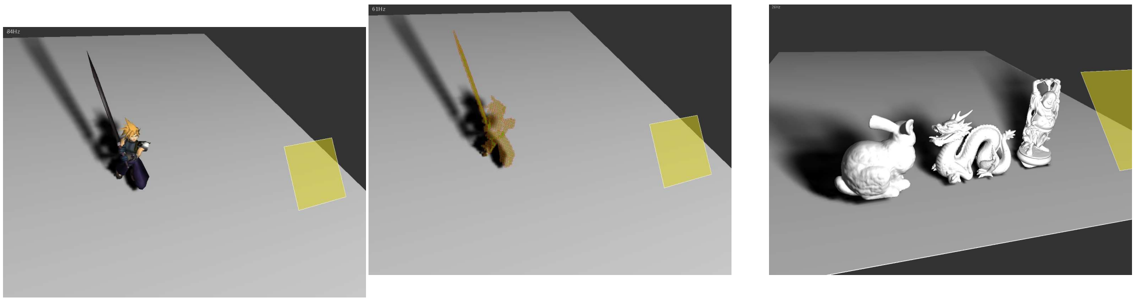
Figure 7. Soft Shadows for ray-tracing, based on soft-shadow volumes. Both pictures were computed 11 times faster than the existing state-of-the-art algorithm for soft shadows in ray-tracing.

Our first contribution is a two-stage method for quickly determining the silhouette edges that overlap an area light source, as seen from the point to be shaded. Secondly, we show that these partial silhouettes of occluders, along with a single shadow ray, are sufficient for reconstructing the visibility function between the point and the light source.

The results (see Figure 7) show very high quality soft shadows, while achieving a significant speedup — in that case, both pictures were computed 11 times faster than the existing state-of-the-art method for computing soft shadows with ray-tracing. This method was published at Siggraph 2005 [6].

6.1.5. Real-Time Soft Shadows using Shadow Maps

We have developped a completely new algorithm for real-time computation of soft shadows. This algorithm is based on the shadow map method [43]. The shadow map is converted into a discrete representation of the occluders (see Figures 8a and 8b), 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 8. 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 8c). 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 submitted for publication in *Computer Graphics Forum* [22].

6.1.6. 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 9. 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 9).

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 submitted for publication to the *Journal of Graphics Tools* [23].

6.1.7. Real-Time Reflexions on Curved Surfaces

We are working on 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 AFIG 2005 conference [20].

6.1.8. 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 11). 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

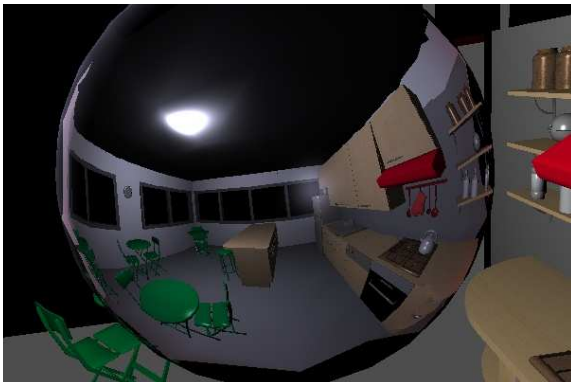


Figure 10. Example of reflexions computed in real-time using our algorithm.

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 12). The paper has been submitted to the Graphics Interface 2006 conference [27] and proposes a new way to model entire objects and scene parts with images.

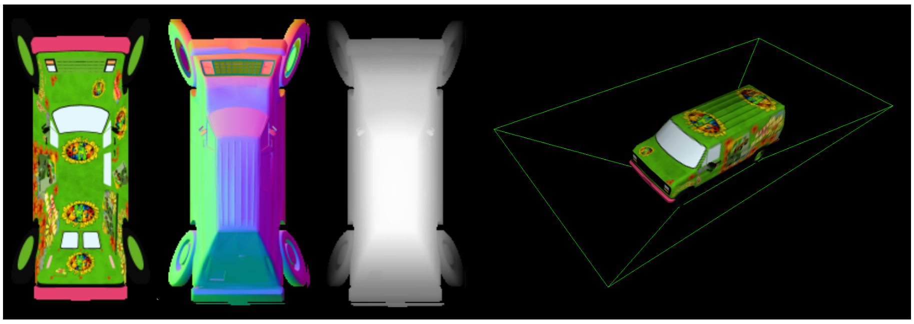


Figure 11. (left) Color, normal and depth textures for a perspective distorted heightfield (right) Rendering of the bounding box with ray-intersection performed in a shader.

6.2. Inverse rendering

Participants: François Sillion, Sylvain Paris, Hector Briceño.

6.2.1. Progressive Surface Reconstruction from Images Using a Local Prior

This year we worked on developing a patch-based progressive surface reconstruction system using a local prior. The primary contribution is the notion of local prior: We argue that an object can be reconstructed piece by piece. Formally, it implies that we optimize an energy function whose definition relies only on a small part of the object whereas most existing techniques involve the whole object in their energy.

This approach combines the advantages of the carving method and of the graph-cut optimization. The former can represent any shape but lacks robustness because it is purely point-wise. The latter is highly accurate and

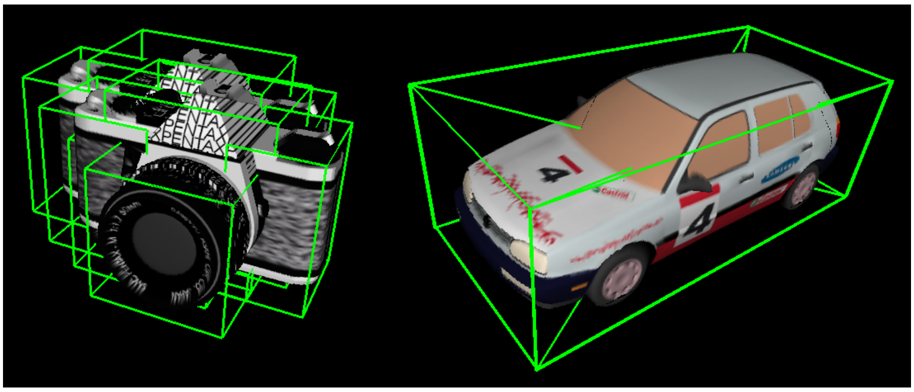


Figure 12. Rendering of an object represented by 6 relief textures.

Figure 13. Results of our patch-based reconstruction technique showing the accuracy of the recovered model.

robust but it cannot handle arbitrary shapes because of the global parameterization it is based on. We use a progressive refinement scheme to recover the topology and reason the visibility of the object. Within each voxel, a detailed surface patch is optimally reconstructed using a graph-cut method. The advantage of this technique is its ability to handle complex shape similarly to level sets while enjoying a higher precision. Compared to carving techniques, the addressed problem is well-posed, and the produced surface does not suffer from aliasing. In addition, our approach seamlessly handles complete and partial reconstructions: If the scene is only partially visible, the process naturally produces an open surface; otherwise, if the scene is fully visible, it creates a complete shape. To our knowledge, this property is unique in the literature. Furthermore, the achieved accuracy compares to the state of the art.

From a theoretical point of view, we have demonstrated that the local approach yields results equivalent to global methods for several classical optimization techniques (level sets, weak membrane and graph cuts). We have also shown that the algorithm is optimal in terms of complexity: as long as the xyz coordinates can be stored on floating-point variables, the memory space required by our technique does not depend on the object size since the patches are processed one at a time. And the time complexity is proportional to the object area, which is proven optimal. These results have to be compared with existing algorithms that use data structures growing proportionally to the object size, and whose time complexity is often more than quadratic. This work has been published at ICCV '05 [21] and in the Internation Journal of Computer Vision [8].

6.3. Visibility

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

6.3.1. On exact visibility

We implemented an original approach for exact polygon-to-polygon visibility query. State-of-the art methods explicitely compute a representation, in 5D space, of the set of rays blocked. In contrast, we search for a non-blocked ray. It can be proven that if such a ray exists, then a particular unblocked ray exist that is quadritangent to the scene (it passes through 4 edges of the polygonal model, including the two tested surfaces). By enumerating such "events" and testing for occlusion with a simple ray/scene query until a non-blocked ray is found, we can solve the visibility query. To avoid the n^4 complexity induced by a naive iteration over the events, we developped various tests, based on the study of possible configurations, that quickly prune many branches of the search tree. The advantage of the methods is that we do not need to compute nor to store the (potentially complex) representation of the blocked ray. Moreover, the basic operation is a ray/scene intersection, which simply requires traversing the triangles one by one and testing them again the ray. Thus, the algorithm does not need to have the scene in main memory and we can perform out-of-core visibility query for large models.

During that work, we discovered that the definition of a blocked ray is ambiguous in the litterature. We constructed the cases that illustrate these ambiguities and from there were able to propose a general unambiguous definition. This work is currently under redaction for submission to a journal.

6.3.2. Fast Scene Voxelization and Applications

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 [14].

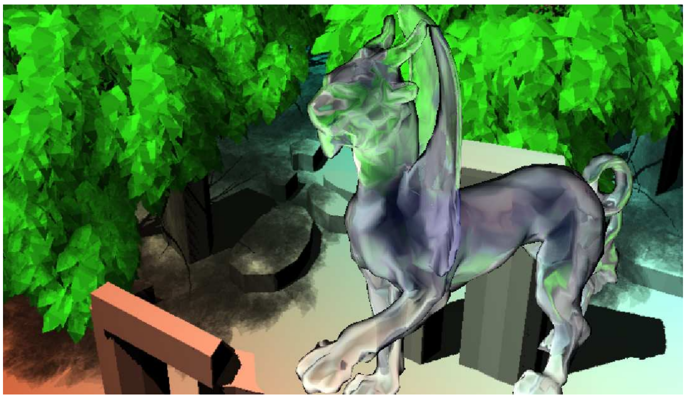


Figure 14. Voxelization on standard graphics hardware allows for rapid, high quality effects

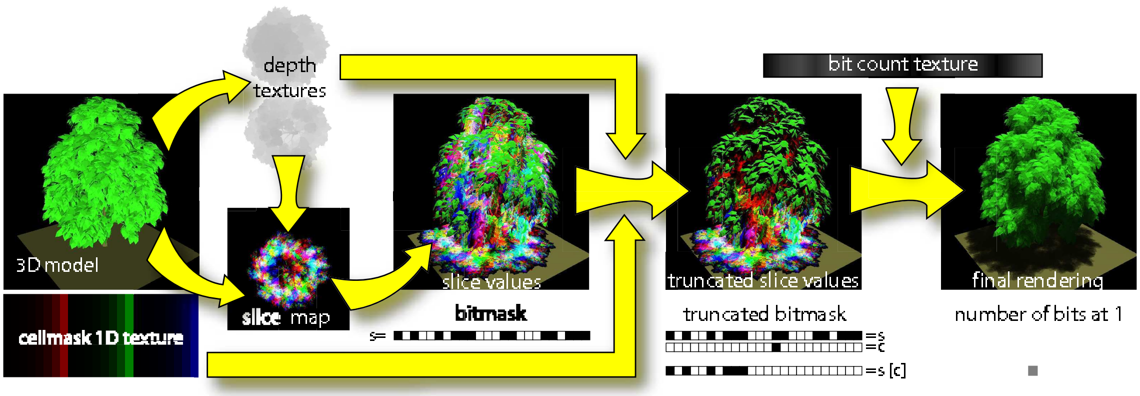
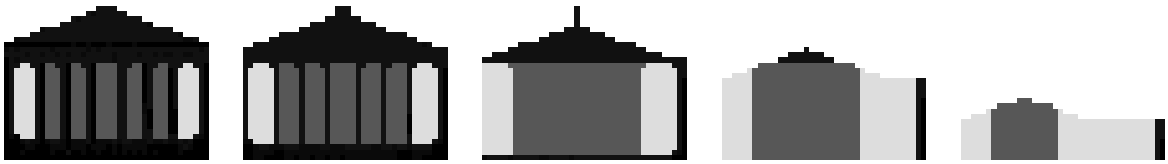


Figure 15. Estimation of attenuation inside foliage based on the voxelization (≈ 30 fps)

6.3.3. N-Buffers

We developped the N-buffer as a tool for multiresolution occlusion testing. This *distance buffer* encodes the value and position of local distance maxima at different scales in an image cube, in contrast to the image pyramid of hierarchical occlusion maps (see fig. 16). The resulting increase in storage space is largely compensated by the following benefits: objects of any size can be culled in constant time against an occlusion map using four depth lookups; N-buffers can be computed very efficiently, and possibly implemented in hardware. We studied the performance gains that can be expected when using N-buffers for occlusion testing in walkthrough applications and showed that they allow a dramatic reduction in the number of depth tests. This work has been presented at EG'05 [5].



level 0 level 1 level 2 level 3 level 4

Figure 16. An exemple of the 5 levels of a N-buffer for an occlusion map of a greek temple

6.3.4. Maintaining visibility information of planar point sets with a moving viewpoint

This work was done in collaboration with Olivier Devillers (INRIA/Geometrica), Vida Dujmović (McGill University, Canada), Hazel Everett (INRIA/Vegas), Sue Whitesides (McGill University) and Steve Wismath (University of Lethbridge, Canada).

Given a set of n points in the plane, we consider the problem of computing the circular ordering of the points about a viewpoint q and efficiently maintaining this ordering information as q moves. This problem is one of the simplest related to visibility problems. We derive an optimal solution to it, using linear size and taking time $O(\log n)$ per event, where an event is either a change in the radial ordering of the points around q, or a change in q's trajectory. Interestingly, the very same algorithm can be applied to the problem of maintaining the n points ordered according to their distance to q.

This work was published in the proceedings of the 17th Canadian Conference on Computational Geometry (August 2005) [13].

6.4. Expressive Rendering

Participants: François Sillion, Jean-Dominique Gascuel, Gilles Debunne, Joëlle Thollot, David Vanderhaeghe, Matt Kaplan, Hedlena Bezerra, Stéphane Grabli, Pascal Barla.

6.4.1. Line simplification and abstraction

Line drawing is an important aspect of modern graphics. It allows an intuitive depiction of complex scenes with a remarkable economy of means. Artists have since long learned to use this perceptual property to provide stunningly expressive pictures, by cleverly tuning line density accross their drawings. However, most of the time in computer graphics, lines do not come with an appropriate density. The reasons for that may be numerous, but they lead to the same observation: there is a need to reduce the number of lines in a drawing, otherwise the effectiveness of such a representation may be compromised. Moreover, there is not a single way to accomplish this task, so we must be able to adapt to the needs of different contexts.

We adress this question by considering a set of vectorized lines in input and producing another set of lines containing fewer lines than the original. This problem arises in many different contexts such as:

- Progressive editing (sometimes called oversketching) where the user refines a curve by successive sketches. This approach is often more natural than control point editing, in particular for "sketch-based modeling".
- Adjusting line density in a drawing. This is needed when scaling a line drawing, as well as when rendering from a 3d scene, where too many lines may project in a given region of the image. In this context only the most "significant" lines should be drawn.
- Creating level-of-detail representations for line-based rendering (contours and hatching), where the number of lines should vary with scale. The main difficulties with all existing methods are the selection of lines and the transition between LODs.

Each of these contexts has its own way for guiding the simplification: for progressive editing the key is ergonomy, usually ensured by a set of heuristic rules that must be known to the user. For density control the goal is to draw the most significant lines while maintaining a limit on image density. With LODs, their creation is guided either by aesthetic considerations or by conservation rules, such as tone preservation for hatching groups.

We propose a common framework for these problems, where simplification is controlled by a single scale parameter ϵ, which has a slight different meaning depending on the application goals.

The results have been published in [10], [11], see Figure 17.

Figure 17. The two stages of our method. Lines of the initial drawing (left) are first automatically clustered into groups that can be merged at a scale ϵ (indicated by the circle diameter in the center image, where each group is assigned a unique color). A new line is then generated for each group in an application-dependent style (at right, line thickness indicates the mean thickness of the underlying cluster).

6.4.2. 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 18.

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 conditionnally accepted to the NPAR '06 conference [12].


(a)


(b)


(c)

Figure 18. Various watercolor-like images obtained either from a 3d model (a,b) or from a photograph (c) in the same pipeline.

6.4.3. 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 19, 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 accepted for publication at the NPAR '06 conference [9] and is the result of the Eurodoc grant obtained by Pascal Barla for his stay in the University of Michigan (see section 8.3.2.1).

Figure 19. 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).

6.4.4. 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 20.

This work has been submitted to NPAR06 [28] and is part of the MIRO project (see section 8.1.4) in collaboration with IPARLA (a project from INRIA Futurs).

6.4.5. Interactive Hatching and Stippling by Example

An important challenge facing researchers in nonphotorealistic rendering (NPR) is to develop hands-on tools that give artists direct control over the stylized rendering applied to drawings or 3D scenes. An additional challenge is to augment direct control with a degree of automation, to relieve the artist of the burden of stylizing every element of complex scenes. This is especially true for scenes that incorporate significant repetition within the stylized elements. While many methods have been developed to achieve such automation algorithmically outside of NPR (*e.g.*, procedural textures), these kinds of techniques are not appropriate for many NPR styles where the stylization, directly input by the artist, is not easily translated into an algorithmic representation. An important open problem in NPR research is thus to develop methods to analyze and synthesize artists interactive input.

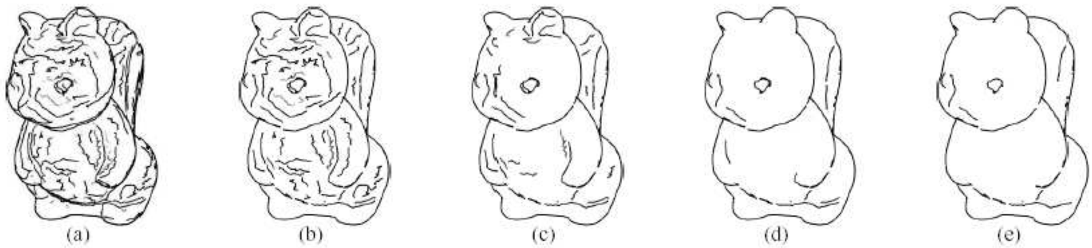


Figure 20. The selection of feature lines. (a) The raw feature lines extracted from the model's geometry; (b),(c),(d),and (e) The feature lines are filtered by the mean of an increasing threshold on our perception-based measure.

In this work, we focus on the synthesis of stroke patterns that represent tone and/or texture. This particular class of drawing primitives have been investigated in the past, but with the goal of accurately representing the tone or texture of a given source image. Instead, we orient our research towards the faithful reproduction of the expressiveness, or style, of an example drawn by the user, and to this end analyze the most common stroke patterns found in illustration and comics: hatching and stippling patterns.

Our goal is thus to synthesize stroke patterns that look like an example pattern input by the artist, and since the only available evaluation method of such a process is visual inspection, we need to give some insights into the perceptual phenomena arising from the observation of a hatching or stippling pattern. In the early 20th century, Gestalt psychologists came up with a theory of how the human visual system structures pictorial information. They showed that the visual system first extracts atomic elements (*e.g.*, lines, points, and curves), and then structures them according to various perceptual grouping criteria such as proximity, parallelism, continuation, symetry, similarity of color, velocity, etc. This body of research has subsequently grown under the name of perceptual organization (see for example the proceedings of POCV, the IEEE Workshop on Perceptual Organization in Computer Vision). We believe it is of particular importance when studying artists inputs.

This work has been submitted to to the Graphics Interface 2006 conference [25] and is the result of the Eurodoc grant obtained by Pascal Barla for his stay in the university of Michigan (see section 8.3.2.1). The results are illustrated in Figure 21.

6.5. Virtual Reality

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

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

6.5.1. 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. This small number of triangles makes the texturing errors more visible.

Several problems arise:

- how to handle the great amount of data represented by the camera images;
- how to decide which part of the 3D model is visible from each camera;

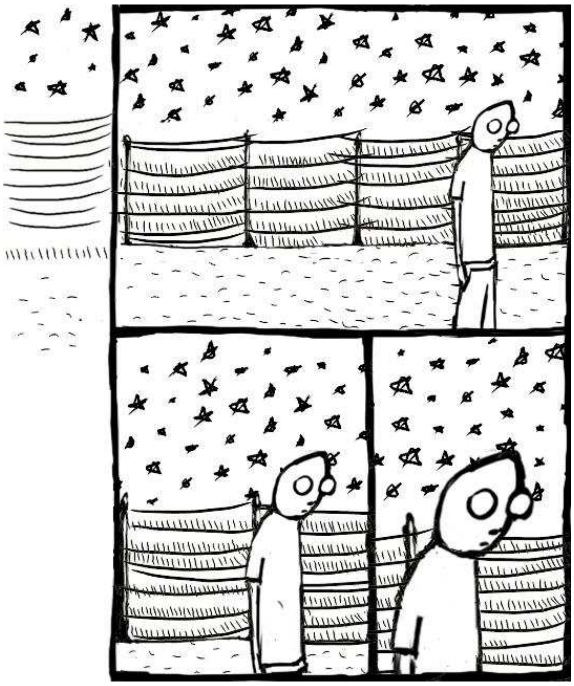


Figure 21. An illustration created with our system. The hatching and stippling patterns on the upper left were inputs for our synthesis method. The user then guided the synthesis process to fill a hand-drawn illustration with similar-looking hatching and stippling patterns.

- how to obtain smooth transitions between adjacent patches, so that the edges are not visible;
- how to choose the set of cameras that will contribute to the texture;
- how to ensure temporal coherence, so that the colors remain the same from one frame to another for each part of the model;

These are problems we are currently working on. We developed a compression method that allows us to transfer only the silhouette data for each frame. We also studied the visibility problem, for which we proposed a solution based on shadow mapping and median filter [19]. Figure 22 illustrates the visibility problem and our results. We have now begun to address the temporal coherence problem.

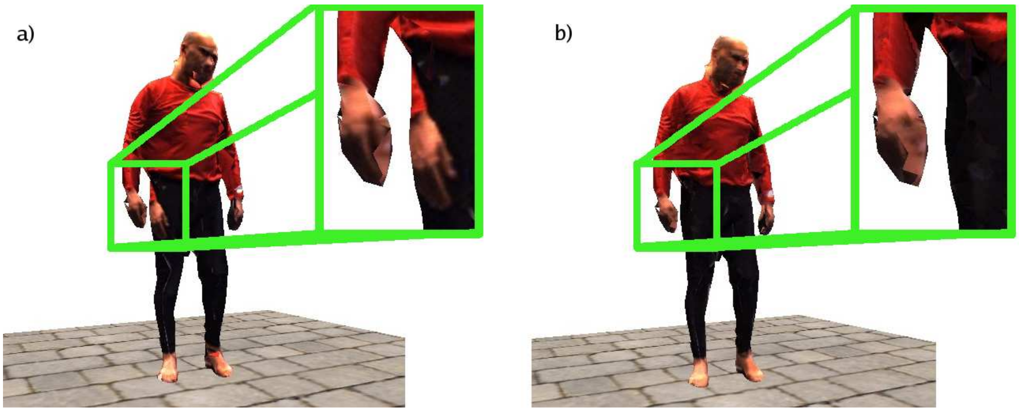


Figure 22. Texturing results: a) texturing without visibility treatment; b) texturing using our algorithm.

6.5.2. 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.

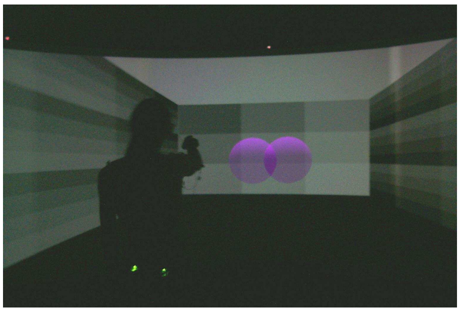


Figure 23. The complexe virtual reality setup used last year: (left) the user pointing at a blue sphere (stereo display on a semi-circular 12x3m screen); (right) The instrumented patient, with devices to record 3D positions, and muscular activations.

This 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. The aim is to provide a stimulation environment as flexible as the hand device, but also suitable to reproduce qualibrated sequences, and to output unbiased and intrinsic measures of the patient ability and progress. We defined a simple VR setup, using a laptop, a video projector, and a few input devices. This work has been published at the XVIIth International Society for Gait and Posture Research Conference [18].

A test on a small sample of well being people should take place in early 2006.

6.6. Geometric analysis

Participants: Samuel Hornus, Aurelien Martinet, Cyril Soler, Nicolas Holzschuch, Francois sillion.

6.6.1. Texture sprites

We propose a representation for efficiently and conveniently storing texture patches on surfaces without parameterization. The main purpose is to texture surfaces at very high resolution while using very little memory: patterns are stored once while instance (*i.e.*, sprites) attributes (pattern number, size, orientation) are stored in an octree-like structure (requiring no surface parameterization). Our representation correctly handles filtering while most other methods suffer from filtering artifacts at patch boundaries. Implemented as texture sprites, the texture patches of a composite texture can be updated dynamically. This provides natural support for interactive editing, and also enables various kinds of animated textures, from wavy stationary features to crawling spots. We extend this basic scheme with two examples which would be difficult to achieve with other methods: complex blending modes between the texture patches, and rigid scales on a deforming surface. Since our representation is particularly well suited for interactive applications and texture authoring applications, we focus in the paper on its GPU implementation, while preserving high-quality rendering, see Fig. 24.

This work has been published in the proceedings of the 2005 Symposium on Interactive 3D Graphics and Games [17], as well as in a technical report [41]. An application of this work to mesh painting has been published in the book *GPU Gems 2* [7].

6.6.2. Semantic analysis of non coherent geometry

Aurélien Martinet started his PhD in 2003, under the supervision of Nicolas Holzschuch and Cyril Soler, working on the automatic extraction of semantic information from non coherent geometry. This 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.

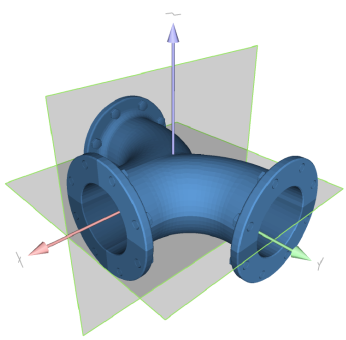
The question to be solved is thus how to automatically retrieve some high level (also named *semantic*) information from a *polygon soup*, *i.e* a list of polygons without any information about how these polygons are related to each other. During the passed year, we have focused on developing a new technique for automaticaly extracting symetries of 3D shapes using a deterministic, yet permissive, algorithm. This not only allows to find symetries with extreme precision in purely symetric models but also approximate symetries which exist in perturbed 3D data such as scanned models. Figure 25 shows an example of automatically computing symetries of a scanned 3D model and retrieving instancing information in a complex 3D scene, as an application to automatic symetry detection. This work has been accepted for publication in the *ACM Transactions on Graphics* journal [24].

7. Contracts and Grants with Industry

7.1. Noveltis

Participants: Cyril Soler [contact], Francois Sillion.

Figure 24. The Stanford bunny is textured using texture sprites. Each clip-art (stars, moon, rocket) are individual sprites that can be animated or generally modified independantly. Yet, rendering of the textured bunny is achieved at high frame-rate (e.g., 60 Hz).



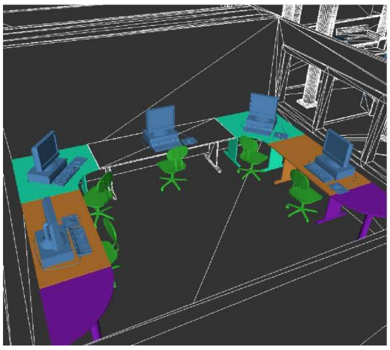


Figure 25. Left: Symetries of this scanned model were automatically retrieved by the technique developped by Aurelien Martinet. Right: Automatic retrieval of instancing information from a polygon soup: all groups of polygons forming chairs have been detected as similar, despite their different position and orientation in the scene.

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 [39].

7.2. CIFRE avec Eden Games

Participants: Nicolas Holzschuch [contact], Lionel Atty, Francois sillion.

We have started 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, is working on rendering photorealistic effects, such as soft shadows, in real-time.

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.

8.2. 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*. This association, now in its third 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 [4] [32], [33], [35], [34], [36] are co-signed by researchers from the two groups).

The activity of the associate team remained high in 2005:

- The line drawing code from S. Grabli [35], [34], [36], developped within this associate team, was turned into a sourceforge project to ease dissemination and support after Stephane's graduation. Results of the line drawing style project have been presented in several talks during F. Sillion's visit in China in April 2005.
- Pascal Barla's research on line drawing simplification, developed in particular during his stay at MIT in April 2004, has been continued and has led to two publications in 2005 [10], [11].
- the project on frequency analysis of light transport culminated in the presentation of a paper at SIGGRAPH [4], which was apparently very well received (mentioned in the highlights of the conference by the program chair).

8.3. International grants

8.3.1. RealReflect

The european RealReflect project (http://realreflect.org/) is a part of the IST-2001-34744 program (http://www.cordis.lu/ist/). This is a research and developement project planned over three years. The goals of the RealReflect project are the development new simulation and visualization methods in the context of Virtual Prototyping (VR), the new techniques, standards and interfaces for data exchange developed in this project being an engine for economic development.

On the technical level the RealReflect project combines aspects of data acquisition for materials and ligth sources, light simulation, and realistic and physically correct visualization in VR-displays. Academic partners of the project are:

- VUT (Vienna University of Technology, Institute of Computer Graphics and Algorithms, Austria);
- UBO (University of Bonn, Institut fur Informatik II, Germany);
- MPI (Max Planck Institut, Computer Graphics Group, Germany);
- UTIA (Czech Academy of Sciences, Institute of Information Theory and Automation, Czech);
- INRIA (Institut National de Recherche en Informatique et Automatique, ARTIS project, France).

Industrial partners are:

- DC (Daimler Chrysler, automotive industry, Germany);
- ICIDO (integration in VR-systems, Germany);
- FAURECIA (supplier for car interiors in Europe, France);
- VRA (VR-Architecs, architecs, Austria).

The role of the ARTIS team in this project are (1) to transfer its scientific knowledge in the domain of simulation of the light equilibrium in complex environments and (2) to develop new methods for obtaining a realistic solution in accordance with the physical data.

During three years, the artis team has developped the Highly Realistic Rendering module of the project. Beyond the integration into the pipeline of the project, the module also exists as a stand-alone software capable of realizing lighting simulations using *photon mapping*. Thanks to its high extensibility, it also provides a very practical test bed for new algorithms related to lighting simulation, sampling and visibility calculation. The Project itself ended in October 2005 and received a very good evaluation from the european commission.

Figure 26 show an example of result produced by the software developed at INRIA in the context of automotive industry.

Figure 26. Example of result produced by the lighting simulation software developed at INRIA in the context of automotive industry for the RealReflect european project. Model courtesy of DaimlerChrysler AG.

8.3.2. Eurodoc 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:

8.3.2.1. University of Michigan

Pascal Barla has been visiting Lee Markosian at the University of Michigan, Ann Arbor, for seven months in 2005. This visit was supported by a grant from the Eurodoc program of Region Rhone-Alpes. During this collaboration, Pascal Barla has worked on two main topics in NPR: extending the toon shader to take into account level fo details (see Section 6.4.3 and stroke patterns synthesis by example (see Section 6.4.5).

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. Artis also collaborates with Coyote Software, a start-up ran by a former Master student and whose project has been accepted by GRAIN (Grenoble [Rhone Aples] Incubation) upon INRIA’s recommendation. Coyote is developing its first game with a business model that favors close contact with research labs in order to rapidly incorporate technological advances. Fruitful discussions have lead to a research subject proposal.

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[8]. A search engine browses all the publications: download is made easy, and all associated documents (images, videos, abstract,

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

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.

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 [36], [34]. 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 '05 and '06, EGSR '05, I3D '05, 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
- Nicolas Holzschuch is a member of the program committee of EGSR '06.

10. Bibliography

Doctoral dissertations and Habilitation theses

[1] S. GRABLI. *Le style dans le rendu non-photoréaliste de dessins au trait à partir de scènes 3D : une approche programmable*, Ph. D. Thesis, Université Joseph Fourier, Université Joseph Fourier - BP 53 - 38041 Grenoble Cedex 9 - FRANCE, March 2005, http://artis.imag.fr/Publications/2005/Gra05.

[2] J.-M. HASENFRATZ. *Insertion temps réel d'un animateur dans un monde virtuel*, Habilitation à Diriger des Recherches, Université Joseph Fourier, Grenoble, October 2005, http://artis.inrialpes.fr/Publications/2005/Has05.

Articles in refereed journals and book chapters

[3] E. CEREZO, F. PEREZ-CAZORLA, X. PUEYO, F. SERON, F. SILLION. *A Survey on Participating Media Rendering Techniques*, in "the Visual Computer", 2005, http://artis.imag.fr/Publications/2005/CPPSS05.

[4] F. DURAND, N. HOLZSCHUCH, C. SOLER, E. CHAN, F. SILLION. *A Frequency Analysis of Light Transport*, in "ACM Transactions on Graphics (Proceedings of the SIGGRAPH conference)", vol. 24, n° 3, August 2005, http://artis.imag.fr/Publications/2005/DHSCS05.

[5] X. DÉCORET. *N-Buffers for efficient depth map query*, in "Computer Graphics Forum (proceedings of Eurographics 2005)", vol. 24, n° 3, 2005, http://artis.imag.fr/Publications/2005/Dec05.

[6] S. LAINE, T. AILA, U. ASSARSSON, J. LEHTINEN, T. AKENINE-MÖLLER. *Soft Shadow Volumes for Ray Tracing*, in "ACM Transactions on Graphics (Proceedings of the SIGGRAPH conference)", 3, vol. 24, August 2005, http://artis.imag.fr/Publications/2005/LAALA05.

[7] S. LEFEBVRE, S. HORNUS, F. NEYRET. *GPU Gems 2: Techniques for Graphics and Compute-Intensive Programming*, ISBN: 0-321-33559-7, chap. Hardware implementation of octree textures, Addison Wesley Professional, March 2005, p. 593–613.

[8] S. PARIS, F. SILLION, L. QUAN. *A Surface Reconstruction Method Using Global Graph Cut Optimization*, in "International Journal of Computer Vision", to appear, 2005, http://artis.imag.fr/Publications/2005/PSQ05.

Publications in Conferences and Workshops

[9] P. BARLA, J. THOLLOT, L. MARKOSIAN. *X-Toon: An extended toon shader*, in "NPAR", to appear, 2006, http://artis.imag.fr/Publications/2006/BTM06a.

[10] P. BARLA, J. THOLLOT, F. SILLION. *Geometric Clustering for Line Drawing Simplification*, in "Siggraph technical sketch: SIGGRAPH'2005", ACM, 2005, http://artis.imag.fr/Publications/2005/BTS05.

[11] P. BARLA, J. THOLLOT, F. SILLION. *Geometric Clustering for Line Drawing Simplification*, in "Proceedings of the Eurographics Symposium on Rendering", 2005, http://artis.imag.fr/Publications/2005/BTS05a.

[12] A. BOUSSEAU, M. KAPLAN, J. THOLLOT, F. X. SILLION. *Interactive watercolor rendering with temporal coherence and abstraction*, in "NPAR", to appear, 2006.

[13] O. DEVILLERS, V. DUJMOVIC, H. EVERETT, S. HORNUS, S. WHITESIDES, S. WISMATH. *Maintaining visibility information of planar point sets with a moving viewpoint*, in "Proc. 17th Canadian Conference on Computational Geometry", 2005, http://artis.imag.fr/Publications/2005/DDEHWW05.

[14] E. EISEMANN, X. DÉCORET. *Fast Scene Voxelization and Applications*, in "Proceedings of I3D'06", to appear, 2006, http://artis.imag.fr/Publications/2006/ED06.

[15] R. GRASSET, L. BOISSIEUX, J.-D. GASCUEL, D. SCHMALSTIEG. *Interactive Mediated Reality*, in "6th Australasian User Interface Conference (AUIC 05), Newcastle, Australia", January 2005, http://artis.inrialpes.fr/Publications/2005/GBGS05.

[16] S. HORNUS, J. HOBEROCK, S. LEFEBVRE, J. C. HART. *ZP+: correct Z-pass stencil shadows*, in "ACM Symposium on Interactive 3D Graphics and Games", ACM Press, ACM, April 2005, http://artis.imag.fr/Publications/2005/HHLH05.

[17] S. LEFEBVRE, S. HORNUS, F. NEYRET. *Texture Sprites: Texture Elements Splatted on Surfaces*, in "Symposium on Interactive 3D Graphics (I3D)", ACM Press, ACM SIGGRAPH, April 2005, http://artis.imag.fr/Publications/2005/LHN05.

[18] O. MARTIN, L. BOISSIEUX, B. JULIAN, J.-D. GASCUEL, C. PRABLANC. *Posture-movement co-ordination when reaching in immersive visual virtual environment*, in "XVIIth International Society for Gait and Posture Research Conference, Marseille, France", Elsevier, June 2005, S19, http://artis.imag.fr/Publications/2005/MBJGP05.

[19] A. ORZAN, J.-M. HASENFRATZ. *Omnidirectional texturing of human actors from multiple view video sequences*, in "Romanian Conference on Computer-Human Interaction", 2005, http://artis.imag.fr/Publications/2005/OH05.

[20] D. ROGER, N. HOLZSCHUCH. *Réflexions spéculaires en temps réel sur des surfaces lisses*, in "AFIG 2005", December 2005.

[21] G. ZENG, S. PARIS, L. QUAN, F. SILLION. *Progressive Surface Reconstruction from Images Using a Local Prior*, in "International Conference on Computer Vision", 2005, http://artis.imag.fr/Publications/2005/ZPQS05.

Internal Reports

[22] L. ATTY, N. HOLZSCHUCH, M. LAPIERRE, J.-M. HASENFRATZ, C. HANSEN, F. SILLION. *Soft Shadow Maps: Efficient Sampling of Light Source Visibility*, submitted to Computer Graphics Forum, Technical report, n° RR-5750, INRIA, November 2005, http://artis.imag.fr/Publications/2005/AHLHHS05.

[23] M. MALMER, F. MALMER, U. ASSARSSON, N. HOLZSCHUCH. *Fast Precomputed Ambient Occlusion for Proximity Shadows*, submitted to the Journal of Graphics Tools, Technical report, n° RR-5779, INRIA, December 2005, http://www.inria.fr/rrrt/rr-5779.html.

[24] A. MARTINET, C. SOLER, N. HOLZSCHUCH, F. SILLION. *Accurately Detecting Symmetries of 3D Shapes*, accepted for publication in ACM Transactions on Graphics, Technical report, nº RR-5692, INRIA, September 2005, http://artis.imag.fr/Publications/2005/MSHS05a.

Miscellaneous

[25] P. BARLA, S. BRESLAV, J. THOLLOT, L. MARKOSIAN, F. SILLION. *Interactive Hatching and Stippling by Example*, 2005, submitted to Graphics Interface ’06.

[26] S. CUNZI, X. DÉCORET, B. RAFFIN, H.-P. PENEL. *Jeux vidéo et réalité virtuelle*, December 2005, Cycle of conferences "What do you really know about it?", organised by the CNAM and the journal "La Recherche".

[27] X. DÉCORET, L. BABOUD. *Real-Time Reflexions on Curved Surfaces*, 2005, submitted to Graphics Interface ’06.

[28] A. LEGEAI, J. THOLLOT, G. THOMAS. *A perception-based criterion for the automatic selection of feature lines*, 2005, submitted to NPAR06.

[29] A. MARTINET, C. SOLER, N. HOLZSCHUCH, F. SILLION. *Accurately Detecting Symmetries of 3D Shapes SGP Poster Session*, June 2005, http://artis.imag.fr/Publications/2005/MSHS05.

[30] D. VANDERHAEGHE. *Un outil de dessin au trait pour le design d’une étude de caractérisation des lignes*, Technical report, Institut National Polytechnique de Grenoble, Université Joseph Fourier, June 2005, http://artis.imag.fr/Publications/2005/Van05.

Bibliography in notes

[31] F. C. CROW. *Shadow Algorithms for Computer Graphics*, in "Computer Graphics (Proceedings of SIGGRAPH 77)", vol. 11, nº 2, July 1977, p. 242–248.

[32] M. CUNZI, J. THOLLOT, S. PARIS, G. DEBUNNE, J.-D. GASCUEL, F. DURAND. *Dynamic Canvas for Immersive Non-Photorealistic Walkthroughs*, in "Proc. Graphics Interface", A K Peters, LTD., june 2003, http://www-artis.imag.fr/Publications/2003/CTPDGD03.

[33] X. DÉCORET, F. DURAND, F. SILLION, J. DORSEY. *Billboard Clouds for Extreme Model Simplification*, in "Proceedings of the ACM Siggraph", ACM Press, 2003, http://www-artis.imag.fr/Publications/2003/DDSD03.

[34] S. GRABLI, F. DURAND, F. SILLION. *Density Measure for Line-Drawing Simplification*, in "Proceedings of Pacific Graphics", 2004, http://artis.imag.fr/Publications/2004/GDS04.

[35] S. GRABLI, F. DURAND, E. TURQUIN, F. SILLION. *A Procedural Approach to Style for NPR Line Drawing from 3D models*, Technical report, nº 4724, INRIA, February 2003, http://www.inria.fr/rrrt/rr-4724.html.

[36] S. GRABLI, E. TURQUIN, F. DURAND, F. SILLION. *Programmable Style for NPR Line Drawing*, in "Rendering Techniques 2004 (Eurographics Symposium on Rendering)", ACM Press, june 2004, http://artis.imag.fr/Publications/2004/GTDS04.

[37] J.-M. HASENFRATZ, M. LAPIERRE, J.-D. GASCUEL, E. BOYER. *Real-Time Capture, Reconstruction and Insertion into Virtual World of Human Actors*, in "Vision, Video and Graphics", Elsevier, Eurographics, 2003, http://www-artis.imag.fr/Publications/2003/HLGB03.

[38] J.-M. HASENFRATZ, M. LAPIERRE, F. SILLION. *A Real-Time System for Full Body Interaction*, in "Virtual Environments", 2004, p. 147-156, http://artis.imag.fr/Publications/2004/HLS04.

[39] J. HELBERT, B. BERTHELOT, C. SOLER. *HYEMALIS: Un Simulateur d'Images de Paysages Tridimensionnels Complexes*, in "Revue Francaise de Photogrammetrie et de Teledetection", n° 173 / 174, Societe Francaise de Photogrammetrie et de Teledetection, November 2003, p. 27–35, http://artis.imag.fr/Publications/2003/HBS03.

[40] P. LALONDE, E. SCHENK. *Shader-driven compilation of rendering assets*, in "ACM Transactions on Graphics (Proceedings of SIGGRAPH 2002)", vol. 21, n° 3, July 2002, p. 713 - 720.

[41] S. LEFEBVRE, S. HORNUS, F. NEYRET. *All-Purpose Texture Sprites*, Technical report, n° 5209, INRIA, May 2004, http://artis.imag.fr/Publications/2004/LHN04.

[42] S. LEFEBVRE, F. NEYRET, S. HORNUS, J. THOLLOT. *MobiNet: a pedagogic platform for Computer Science, Maths and Physics (How to make students love Maths by programming video games)*, in "Eurographics - Education", Grenoble, Eurographics, August 2004, http://artis.imag.fr/Publications/2004/LNHT04.

[43] L. WILLIAMS. *Casting Curved Shadows on Curved Surfaces*, in "Computer Graphics (Proceedings of SIGGRAPH 78)", vol. 12, n° 3, August 1978, p. 270–274.