INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

# *Project-Team artis*

# *Acquisition, representation and transformations for image synthesis*

*Grenoble - Rhône-Alpes*

Theme : Interaction and Visualization

Activity Report

2010

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

# 1. Team

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# 2. Overall Objectives

## 2.1. Overall Objectives

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

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

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

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

# 3. Scientific Foundations

## 3.1. Introduction

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

## 3.2. Lighting and Rendering

**Participants:** Lionel Atty, Cyril Crassin, Nicolas Holzschuch, David Roger, Charles de Rousiers, Cyril Soler, Kartic Subr, Mahdi Mohammad-bagher, Olivier Hoel, Isabelle Delore.

Glossary

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

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

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

### 3.2.1. Lighting simulation

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

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

#### *3.2.1.1. Image realism*

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

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

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

#### *3.2.1.2. Computation efficiency*

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

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

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

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

### 3.2.2. Inverse rendering

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

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

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

## 3.3. Expressive rendering

**Participants:** Pierre Bénard, Hedlena Bezerra, Adrien Bousseau, Pierre-Edouard Landes, Thomas Hurtut, Alexandrina Orzan, Thierry Stein, Cyril Soler, Joëlle Thollot.

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

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

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

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

## 3.4. Computational Photography

**Participants:** Kartic Subr, Adrien Bousseau, Cyril Soler.

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

## 3.5. Guiding principles

We base our research on the following principles:

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

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

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

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

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

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

### *3.5.4. User friendliness*

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

# 4. Application Domains

## 4.1. Illustration

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

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

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

## 4.2. Video games and visualization

Video games represent a particularly challenging domain of application since they require both real-time interaction and high levels of visual quality. Moreover, video games are developed on a variety of platforms with completely different capacities. Automatic generation of appropriate data structures and runtime selection of optimal rendering algorithms can save companies a huge amount of development (*e.g.* the EAGL library used by Electronic Arts [28]).

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

## 4.3. Virtual heritage

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

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

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

# 5. Software

## 5.1. Introduction

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

## 5.2. libQGLViewer: a 3D visualization library

**Participant:** Gilles Debunne [contact].

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

## 5.3. PlantRad

**Participants:** Cyril Soler [contact], François Sillion.

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

## 5.4. High Quality Renderer

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

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

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

## 5.5. MobiNet

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

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

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

## 5.6. Basilic : an Automated Bibliography Server

**Participant:** Gilles Debunne [contact].

Basilic is a tool that automates the diffusion of research results on the web. It automatically generates the publication part of a project web site, creating index pages and web pages associated to each publication. These pages provide access to the publication itself, its abstract, associated images and movies, and anything else via web links [4].

All bibtex related information is stored in a database that is queried on the fly to generate the pages. Everyone can very easily and quickly update the site, thus guaranteeing an up-to-date web site. BibTeX and XML exports are available, and are for instance used to generate the bibliography of this activity report. Basilic is released under the GPL licence and is freely available for download [5].

## 5.7. XdkBibTeX : parsing bibtex files made easy

**Participant:** Xavier Décoret [contact].

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

The long term goal is to replace the bibtex program and its associated BST language for style files by a more recent and powerful scripting language (such a Python, Ruby, Php, Perl...) or by Java. The other goal is to allow easy writing of BibTeX related tools such as converters to other format. XdkBibTeX is used by Basilic to import from bibtex files. XdkBibTeX is released under the GPL licence and is freely available for download [6]

[2] http://artis.imag.fr/~Cyril.Soler/HQR
[3] http://mobinet.inrialpes.fr
[4] See for instance http://artis.inrialpes.fr/Publications
[5] http://artis.imag.fr/Software/Basilic
[6] http://artis.imag.fr/Membres/Xavier.Decoret/resources/xdkbibtex/

## 5.8. Freestyle

Freestyle is a software for Non-Photorealistic Line Drawing rendering from 3D scenes. It is designed as a programmable interface to allow maximum control over the style of the final drawing: the user "programs" how the silhouettes and other feature lines from the 3D model should be turned into stylized strokes using a set of programmable operators dedicated to style description. This programmable approach, inspired by the shading languages available in photorealistic renderers such as Pixar's RenderMan, overcomes the limitations of integrated software with access to a limited number of parameters and permits the design of an infinite variety of rich and complex styles. The system currently focuses on pure line drawing as a first step. The style description language is Python augmented with our set of operators. Freestyle was developed in the framework of a research project dedicated to the study of stylized line drawing rendering from 3D scenes. This research has lead to two publications [27], [26].

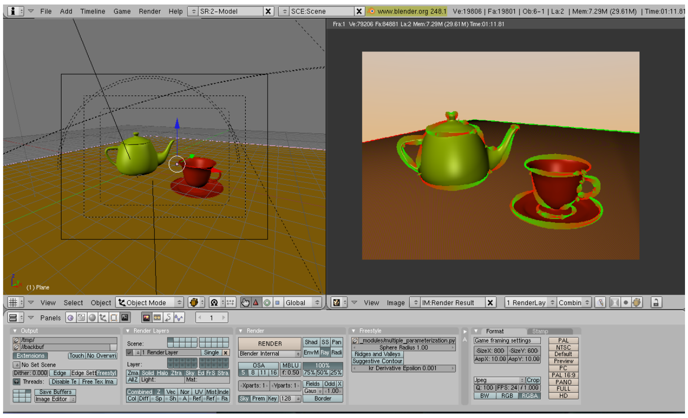

*Figure 1. As a GPL and OpenSource software, Freestyle get a new life from the blender developer community.*

In 2008, Freestyle get a new life, completely outside ARTIS or INRIA: it was the basis of one of the 6 *Google Summer of Code* projects awarded to the *Blender Foundation* [7]! The goal of the project was to integrate Freestyle to the well known free 3D modeler *Blender*, as its standard NPR line-drawing renderer. Maxime Curioni [8] (under the mentoring of Jean-Luc Peurière from the *Blender Foundation*), is currently making the integration. First beta versions are publicly available, and tested by enthusiasts around the web.

## 5.9. Diffusion Curves

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

We provide an implementation of the vector drawing tool described in the 2008 Diffusion Curves Siggraph paper. This prototype is composed of the Windows binary, along with the required shader programs (ie. in source code). The software is available for download [9] for free, for non-commercial research purposes.

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

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

[7] http://www.blender.org/
[8] http://maximecurioni.com/freestyle/?page_id=2
[9] http://artis.imag.fr/Publications/2008/OBWBTS08


*Figure 2. Diffusion curves freely downloadable demo.*

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

TiffIO has been downloaded by a large number of developer, and integrated in a variety of commercial or internal tools, such as by *Pixar*. TiffIO is freely available for download [10].

## 5.11. VRender: vector figures

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

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

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

VRender is also responsible for the vectorial snapshot feature of the QGLViewer library. VRender is released under the LGPL licence and is freely available for download [11].

## 5.12. SciPress

**Participant:** Xavier Décoret [contact].

SciPres is a system for creating animated presentations. It was inspired by Slithy, a python-based system developped by Douglas Zonker. In short, SciPres is to PowerPoint what LaTeX is to Microsoft Word: you script your presentation using a text editor, rather than using a WYSIWYG system. SciPres is released under the GPL licence and is freely available for download [12].

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

# 6. New Results

## 6.1. Lighting and Rendering

**Participants:** Nicolas Holzschuch, Charles de Rousiers, François Sillion, Cyril Soler, Kartic Subr.

### *6.1.1. Real-time Rendering of Heterogeneous Translucent Objects with Arbitrary Shapes*

**Participants:** Nicolas Holzschuch, Kartic Subr.

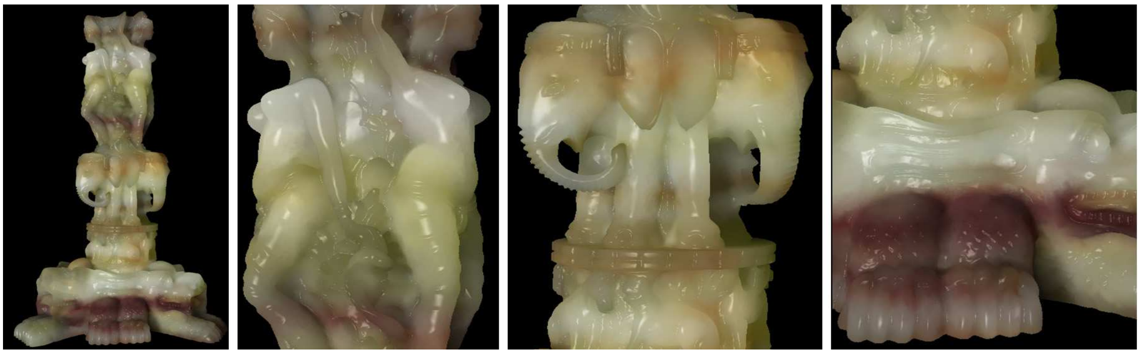

*Figure 3. Rendering results at 22 frames per-second of the Stanford Thai Statue (157 K triangles) with our system.*

Subsurface scattering of light is a complex phenomenon that occurs in many materials such as jade, marble and human skin. It plays an important role in the realism of rendered scenes, but unfortunately is also challenging to simulate. In translucent objects, the outgoing radiance at each point on the surface depends on three factors: Incoming radiance at all points on the surface, the path followed by the light inside the object as well as the optical properties along this path.

In this context we designed a real-time algorithm for rendering translucent objects of arbitrary shape (see Figure 3). We approximate the light scattering process inside the object with the diffusion equation, which we solve on-the-fly using the GPU. Our algorithm is general enough to handle arbitrary geometry, heterogeneous materials, deformable objects and modifications of lighting, all in real-time. Our algorithm works as follows: in a pre-processing step, we discretize the object into a regular 4-connected structure (QuadGraph). Thanks to its regular connectivity, this structure is easily packed into a texture and stored on the GPU. At runtime, we use the QuadGraph stored on the GPU to solve the diffusion equation, in real-time, taking into account the varying input conditions: the incoming light and the object material and geometry. We handle deformable objects, as long as the deformation does not change the topological structure of the objects. This work has been published at the Eurographics conference [14].

### *6.1.2. Stable Inverse Dynamic Curves*

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

2D animation is a traditional but fascinating domain that has recently regained popularity both in animated movies and video games. We propose a method for automatically converting a smooth sketched curve into a 2D dynamic curve at stable equilibrium under gravity (see Figure 4). The curve can then be physically animated to produce secondary motions in 2D animations or simple video games. Our approach proceeds in two steps. We first present a new technique to fit a smooth piecewise circular arcs curve to a sketched curve. Then we show how to compute the physical parameters of a dynamic rod model (super-circle) so that its stable rest shape under gravity exactly matches the fitted circular arcs curve. We demonstrate the interactivity and controllability of our approach on various examples where a user can intuitively setup efficient and precise 2D animations by specifying the input geometry. This work has been published at the SIGGRAPH Asia conference [13].

*Figure 4. The user sketches a smooth curve over the tail of a character. The curve is automatically converted into a dynamic rod model at stable equilibrium under gravity. The user can then animate the curve (e.g., pull then release it) with the guarantee that the chosen initial shape will be preserved after slight (or possibly strong) motion.*

## 6.2. GPU Rendering

**Participants:** Cyril Crassin, Jean-Dominique Gascuel, Nicolas Holzschuch, Fabrice Neyret.

### *6.2.1. Screen-Space Indirect Illumination for Video Games*

**Participants:** Cyril Soler, Olivier Hoel, Franck Rochet.

Computing indirect lighting in video games simultaneously improves gameplay and scene realism. However, the context of 3D video games grings very restrictive constraints: the compution should be very fast and with a constant cost, the indirect illumination algorithm should work with seamlessly on dynamic scenes, with any light sources, and the computed result may be approximate but must be artifact free and temporally coherent.

In this context we present a deferred shading algorithm for computing screen-space multi-bounce indirect illumination with visibility, in real time (see Figure 5). For each frame, we compute mipmapped G-Buffers of depth, normals, illumination and voxelized geometry. To each mipmap level we apply a single shader that gathers screen-space illumination using local Monte-Carlo integration. We upsample the illumination for all levels and smoothly combine them together. Our calculation is approximate but does not show artifacts, because it relies on noise-free Monte-Carlo integration of incoming illumination and temporal filtering. Our method simulates arbitrary distant illumination including visibility at a very low cost, because we only perform local texture lookups during computation. Besides, its deferred shading nature makes it independent of geometric and lighting complexity. This work has been presented as a Talk at the SIGGRAPH conference [21].

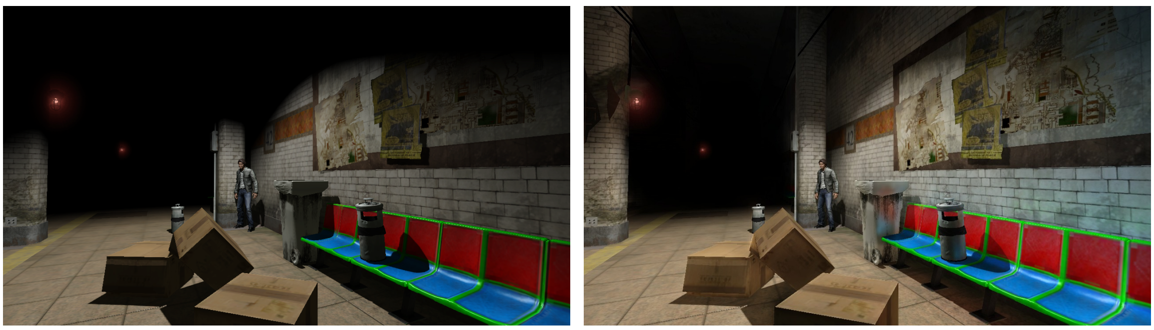

*Figure 5. Left: Direct illumination only. Right: Indirect illumination added by our technique.*

### 6.2.2. Screen-Space Percentage-Closer Soft Shadows

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

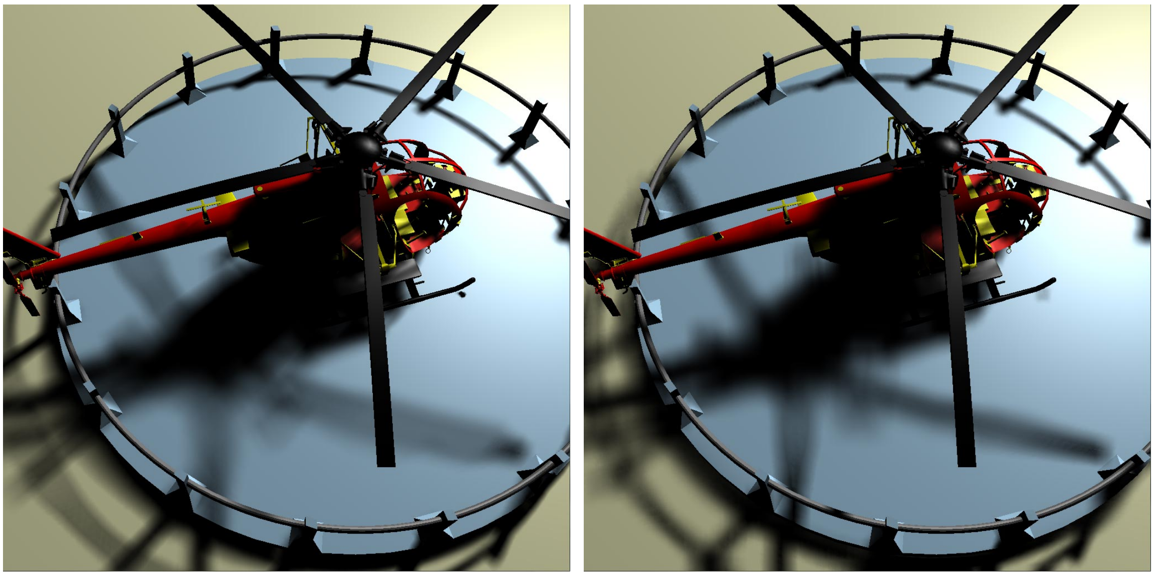

*Figure 6. Left: percentage closer soft shadows. Right: screen-space percentage closer soft shadows.*

We present an algorithm for computing Percentage-Closer Soft Shadows inside a screen-space rendering loop (see Figure 6). Our algorithm is faster than traditional soft shadows based on percentage closer filtering, while providing soft shadows of similar visual quality. It combines naturally with a deferred shading pipeline, making it an ideal choice for video games. This algorithm is not only faster, but allows the use of larger shadow maps without dramatically affecting the rendering speed. This work has been presented has a Poster at the SIGGRAPH conference [20].

### 6.2.3. Real-time rendering of large detailed volumes

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

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

The new method is based on a dynamic $N^3$ tree storing MIP-mapped 3D texture bricks in its leaves. We load on the fly on GPU only the necessary bricks at the necessary resolution, taking into account visibility. This maintains low memory consumption during interactive exploration and minimizes data transfer (See Figure 7). Our ray marching algorithm benefits from the multiresolution aspect of our data structure and provides real-time performance. This work has been published as a book chapter in *GPU Pro (ShaderX 8)* [22].

### 6.2.4. Real-time realistic ocean lighting

**Participant:** Fabrice Neyret.

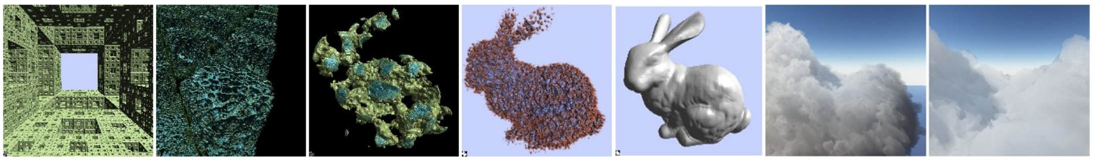

*Figure 7. Various complex large and detailled scenes which our method allows for the interactive exploration despited their voxelisation far exceed the GPU memory.*

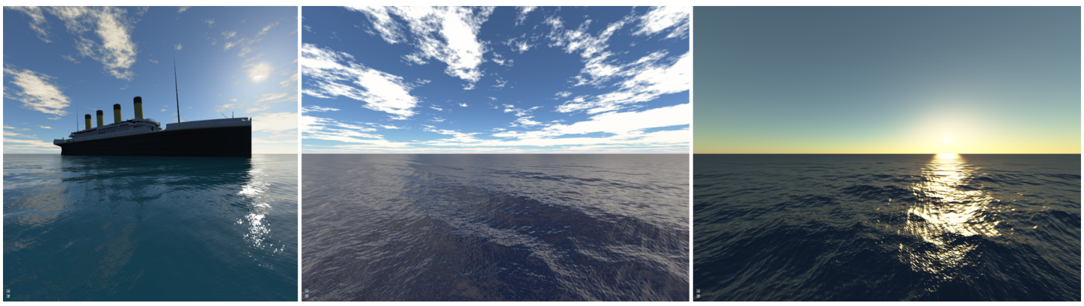

*Figure 8. Some real-time results obtained with our ocean lighting algorithm, showing Sun reflections, sky reflections and local reflections from a boat. The lighting is correct at all distances thanks to accurate transitions from geometry to BRDF.*

In collaboration with Eric Bruneton at Evasion project-team, we developped a new algorithm for modelling, animation, illumination and rendering of the ocean, in real-time, at all scales and for all viewing distances. Our algorithm is based on a hierarchical representation, combining geometry, normals and BRDF. For each viewing distance, we compute a simplified version of the geometry, and encode the missing details into the normal and the BRDF, depending on the level of detail required. We then use this hierarchical representation for illumination and rendering. Our algorithm runs in real-time, and produces highly realistic pictures and animations (see Figure 8). This work has been published at the Eurographics conference [11].

## 6.3. Expressive Rendering

**Participants:** Pierre Bénard, Hedlena Bezerra, Adrien Bousseau, Pierre-Edouard Landes, Alexandrina Orzan, Thierry Stein, Cyril Soler, Joëlle Thollot.

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

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

Texturing an animated fluid is a useful way to augment the visual complexity of pictures without increasing the simulation time. But texturing flowing fluids is a complex issue, as it creates conflicting requirements: we want to keep the key texture properties (features, spectrum) while advecting the texture with the underlying flow — which distorts it. In this context we present a new, Lagrangian, method for advecting textures: the advected texture is computed only locally and follows the velocity field at each pixel (see Figure 9). The texture retains its local properties, including its Fourier spectrum, even though it is accurately advected. Due to its Lagrangian nature, our algorithm can perform on very large, potentially infinite scenes in real time. Our experiments show that it is well suited for a wide range of input textures, including, but not limited to, noise textures. This work has been published in the IEEE Transactions on Visualization and Computer Graphics (TVCG) [15].

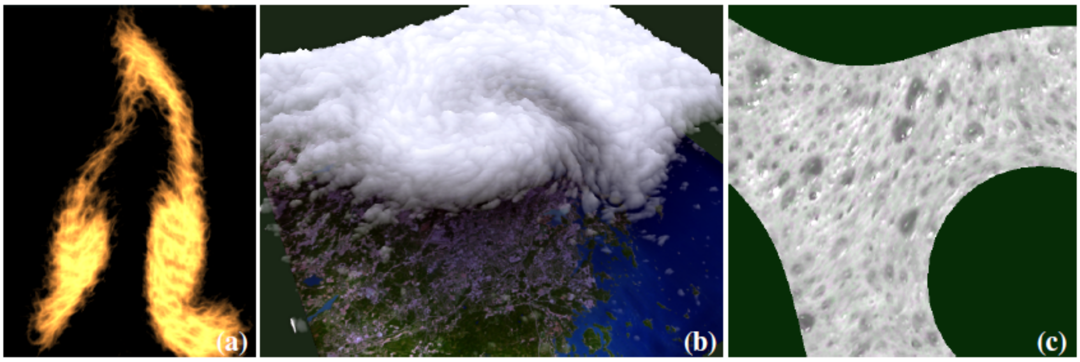


*Figure 9. Results of our method to texture animated fluids. We use as input a velocity field and a texture. We produce as output an animated fluid texture. Left: an input procedural noise (flownoise) texture is advected and used in a procedural fire shader. Middle: an advected procedural noise (flownoise) texture is used in a cloud shader with displacement mapping. Right: advection of an input bubble texture in a river flow.*

### *6.3.2. A Dynamic Noise Primitive for Coherent Stylization*

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

*Figure 10. A variety of styles produced with our method.*

We present a new solution for temporal coherence in non-photorealistic rendering (NPR) of animations (see Figure 10). Given the conflicting goals of preserving the 2D aspect of the style and the 3D scene motion, any such solution is a trade-off. We observe that primitive-based methods in NPR can be seen as texture-based methods when using large numbers of primitives, leading to our key insight, namely that this process is similar to sparse convolution noise in procedural texturing. Consequently, we present a new primitive for NPR based on Gabor noise, that preserves the 2D aspect of noise, conveys the 3D motion of the scene, and is temporally continuous. We can thus use standard techniques from procedural texturing to create various styles, which we show for interactive NPR applications. We also present a user study to evaluate this and existing solutions, and to provide more insight in the trade-off implied by temporal coherence. The results of the study indicate that maintaining coherent motion is important, but also that our new solution provides a good compromise between the 2D aspect of the style and 3D motion. This work has been published at the Eurographics Symposium on Rendering [12], and has been presented as a Talk at the SIGGRAPH conference [19].

### *6.3.3. Diffusion Constraints for Vector Graphics*

**Participants:** Hedlena Bezerra, Joëlle Thollot.

The formulation of Diffusion Curves [Orzan et al. 2008] allows for the flexible creation of vector graphics images from a set of curves and colors: a diffusion process fills out the parts of the image that are away from curves. However, this model has limitations in certain situations and does not always seem to agree with how an artist wants to use the software. First, the diffusion itself cannot be controlled, only the colors. Further, the fact that color needs to be defined everywhere along the curve can lead to tedious and nonintuitive interactions. In this context we present a number of adaptations to diffusion curves that constrain how color is spread across the image (see Figure 11). Specifically, we argue for the utility of controlling the speed and direction of the color diffusion, and the ability to have barriers that can be defined without the need to specify a particular color along these curves. We also describe how this can be implemented by solving a linear system, and demonstrate the effectiveness of our solution on a number of examples. This work has been published at the International Symposium on Non-photorealistic Animation and Rendering (NPAR) [17], and has been presented in an INRIA research report [23].

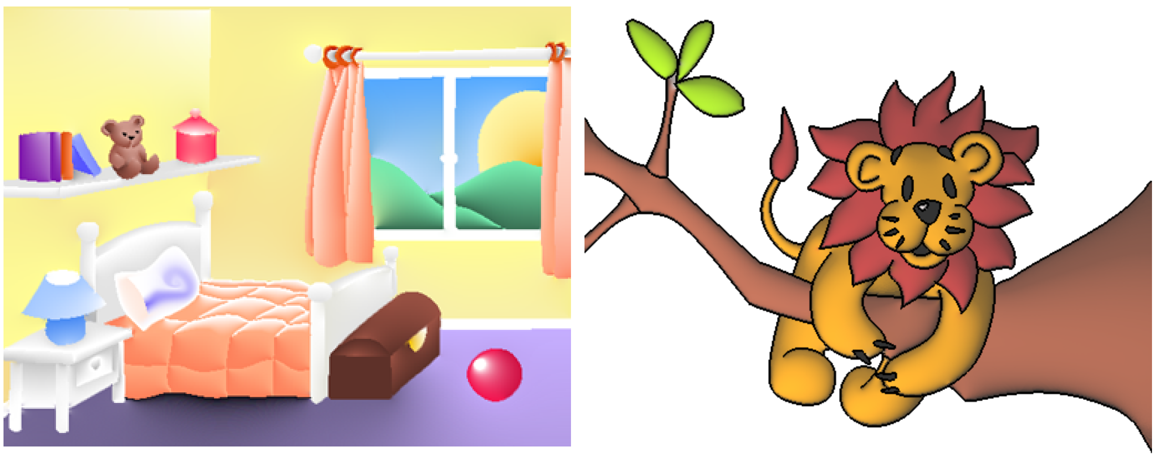

*Figure 11. Diffusion Curves allow us to draw vectorial images with a rich set of color gradients (left). It is based on a diffusion process that propagates color information from curves in the scene. While the colors could be chosen arbitrarily, the diffusion itself is not controllable by the user. Our work introduces ways to alter diffusion behavior. This allows us to reduce the number of color definitions for an equivalent, to control the diffusion strength of certain colors, or even influence diffusion directions. Our approach can diffuse not only colors (left), but also normals for relighting purposes (right).*

### 6.3.4. Automatic Pen-and-Ink Illustration of Tone, Gloss, And Texture

**Participants:** Cyril Soller, Joëlle Thollot.

*Figure 12. Consistent and differentiable depiction of increasing gloss. Because our material abstraction parameters convey a comprehensive understanding of gloss effect at large scales, we are able to render it appropriately using pen and ink.*

We present a method for automatically depicting material appearance using pen and ink (see Figure 12). Starting from a classical computer graphics representation – color map, normal map, illumination, etc. – we introduce an abstraction layer to bridge between this unsuited input and generic control parameters of pen-and-ink systems, such as primitive shape, size and density. This layer is made of parameters, belonging to tone, gloss and texture categories, that are automatically extracted from the input data. We then demonstrate our approach by presenting how this abstraction layer can easily be used to drive an example pen-and-ink rendering system. We show results on various materials, and validate our choices in a user study. This work has been presented in an INRIA research report [24].

### 6.3.5. Self-Similar Texture for Coherent Line Stylization

**Participant:** Pierre Bénard.

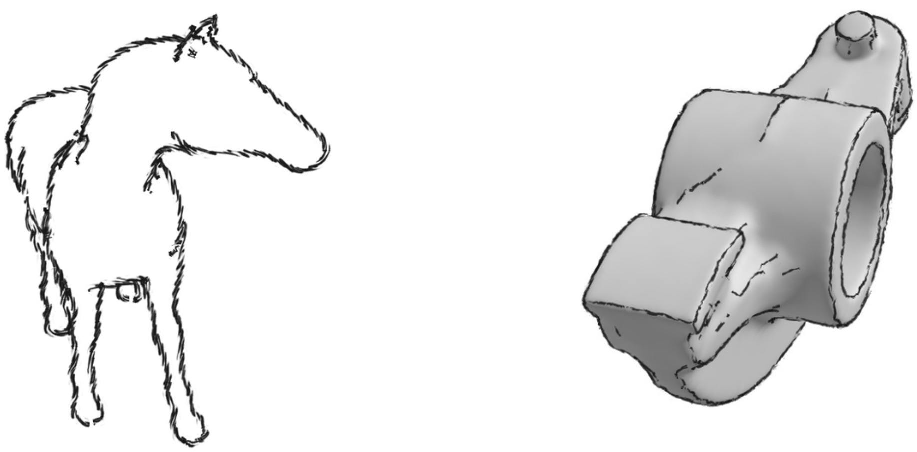

*Figure 13. Shapes drawn with stylized lines using self-similar textures. At different scales the lines appear qualitatively similar, and transitions exhibit temporal coherence.*

Stylized line rendering for animation has traditionally traded-off between two undesirable artifacts: stroke texture sliding and stroke texture stretching. We propose a new stroke texture representation, the self-similar line artmap (SLAM), which avoids both these artifacts (see Figure 13). SLAM textures provide continuous, infinite zoom while maintaining approximately constant appearance in screen-space, and can be produced automatically from a single exemplar. SLAMs can be used as drop-in replacements for conventional stroke textures in 2D illustration and animation. Furthermore, SLAMs enable a new, simple approach to temporally coherent rendering of 3D paths that is suitable for interactive applications. We demonstrate results for 2D and 3D animations. This work has been published at the International Symposium on Non-photorealistic Animation and Rendering (NPAR) [18].

# 7. Contracts and Grants with Industry

## 7.1. GARDEN

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

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

# 8. Other Grants and Activities

## 8.1. ANR Blanc: HFIBMR

**Participants:** Nicolas Holzschuch, Lionel Baboud.

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

## 8.2. ANR MDCO: ATROCO

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

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

## 8.3. ANR RIAM: CHEVEUX

**Participants:** Joëlle Thollot, Hedlena Bezerra.

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

## 8.4. ANR jeune chercheur: Animaré

**Participants:** Hedlena Bezerra, Thomas Hurtut, Pierre Bénard, Adrien Bousseau, Alexandrina Orzan, Pierre-Edouard Landes, Joëlle Thollot.

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

## 8.5. ANR jeune chercheur: SimOne

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

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

## 8.6. ANR CONTINT: RTIGE

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

We are funded by the ANR CONTINT (Contents and Interactions) research program, for a joint research project with the *EVASION* INRIA project-team, the *GEPI* and *LERMA* research teams at Paris Observatory, and the RSA Cosmos company. The goal of this project is to develop a "Real-Time and Interactive Galaxy for Edutainment", in particular for digital planetariums. The grant started in December 2010, for 48 months.

## 8.7. LIMA

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

## 8.8. Association with Cornell University and MIT

**Participants:** Nicolas Holzschuch, Cyril Soler, Kartic Subr.

In 2009, we have started a new Associate Team with the Program of Computer Graphics at Cornell University, on the subject of new challenges in Photorealistic rendering. The Associate Team was quite productive in its first year, with one Siggraph paper[13]

In January 2010, this Associate Team was extended to also include our cooperation with MIT CSAIL. During 2010, we have focused on the following three items:

- Self-similar textures for coherent line stylization, a work in cooperation with MIT. This work is in cooperation with Forrester Cole (post-doc at MIT) and Adam Finkelstein (professor at Princeton), and resulted in a publication at NPAR 2010.
- Light interaction inside meso-structure elements, a work in cooperation with Cornell University. Our goal is to model the interaction of light inside complex meso-structures in a compact way. This research is done in cooperation with Kavita Bala and Bruce Walter of Cornell University, and should result in a publication submitted soon.
- Covariance analysis of light transport in several dimensions, a work in cooperation with Fredo Durand at MIT. Our goal is to conduct a frequency analysis of light transport in several dimensions (space and time), while keeping a trace of the connections between the dimensions, and thus adapting the sampling. This work should result in a publication in 2011.

[13] ...

## 8.9. Cooperation with Adobe Research Center

**Participants:** Joëlle Thollot, Adrien Bousseau, Alexandrina Orzan.

We have started a cooperation with David Salesin of the Adobe Research Center in Seattle. This cooperation has resulted in extended stays of Alexandrina Orzan and Adrien Bousseau in Seattle in 2008, and two publications. In 2009, we continued this cooperation, with two new publications accepted, including one at the Siggraph Asia 2009 conference [25], [29].

## 8.10. Cooperation with Weta Digital

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

The WetaFX company in New Zealand bought an evaluation version of our GigaVoxel software and hosted Cyril Crassin during 3 monthes to study the adaptation of GigaVoxel to their workflow.

## 8.11. Cooperation with Useful Progress

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

The Useful Progress company in France bought an evaluation copy of our GigaVoxel software and a short support for integrating it in their software.

## 8.12. Exploradoc grants at nVidia, London, UK

**Participant:** Cyril Crassin.

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

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

# 9. Dissemination

## 9.1. Thesis and HDR defended in 2009

### *9.1.1. PhD Thesis: Thierry Stein*

Creating a sequence of images that illustrates an animation is a task that finds applications in many fields, from comics to assembly schemes. Such a representation is based on the projection of 3D plus time data to 2D and necessarily involves loss of information. Compensation for this loss is generally handmade and is currently performed on an individual case basis. The objective of Thierry Stein's PhD thesis is to develop algorithms to automate this task as generally as possible. In this context, we are interested in pictorial visualization of particle animations by identifying and illustrating their aggregate movement. For animations taking place in a specific geometrical context, we propose a method to display this context while taking into account the animation summary. Finally, to enhance our pictures with textual or contextual information, we studied the problem of dynamic labeling of 3D scenes and the associated problems of temporal discontinuities and incoherence.

#### *9.1.2. PhD Thesis: Hedlena Bezerra*

Hedlena Bezerra's PhD thesis demonstrates that the computer can be placed as an incomparable assistant into the visual creation process once well-adapted interaction systems are provided. Adaptation is thus an important aspect because, in different levels, users want to be able to have the control over the result in order to give their touch and express their creativity. The thesis presents two different scenarios demonstrating that controllability plays a major role in expressiveness: a real-time technique to cluster a dynamic 3D scene in order to achieve an automatic, yet controllable output that can then be used as input to any rendering style; and a number of adaptations to a drawing vector graphics primitive called Diffusion Curves that constrain and control the creation of complex color gradients. The thesis proposes, on one hand, mathematical and computational well-adapted representations to provide the user with different levels of control over algorithms of expressive rendering in order to manipulate two- and tridimensional scenes; and, on the other hand, to reproject this technical support into user-friendly software solutions.

### 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 [14]. A search engine browses all the publications: download is made easy, and all associated documents (images, videos, abstract, bibTex...) are also available. This kind of local bibliographic tool is not widely spread in the academic community, and we tried to make our system easy to distribute (see section 5.6), so that it can be shared.

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

### 9.3. Other activities

- Nicolas Holzschuch is:
  - Member of the program committee of EG 2010,
  - Member of the program committee of the Eurographics Symposium on Rendering 2010 and 2011,
  - Member of the "Commission d'evaluation" of INRIA.
- Joëlle Thollot is:
  - Member of the program commitee of NPAR 2010.

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