IN PARTNERSHIP WITH:
CNRS

Institut polytechnique de Grenoble

Université Joseph Fourier (Grenoble)

Activity Report 2012

Team MAVERICK

Modèles et Algorithmes pour la Visualisation et le Rendu

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Interaction and Visualization

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Team MAVERICK

Keywords: 3d Modeling, Computer Graphics, Rendering, Visualization

Maverick is both an Inria project-team and a team 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).

Creation of the Team: January 01, 2012 .

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Romain Vergne [Maître de conférence, UJF, from Sept. 2012]
Charles Hansen [Visiting Professor, University of Utah, from Nov. 2011]

Engineers

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Henri Payno [Ingénieur, until November 2012]
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Eric Heitz [MESR]
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Mahdi Bagher [GARDEN (PhD defended November 2012)]
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2. Overall Objectives

2.1. Introduction

Computer-generated pictures and videos are now ubiquitous: both for leisure activities, such as special effects in motion pictures, feature movies and video games, or for more serious activities, such as visualization and simulation.

Maverick was created in January 2012 and deals with image synthesis methods. We place ourselves at the end of the image production pipeline, when the pictures are generated and displayed (see figure 1). We take many possible inputs: datasets, video flows, pictures and photographs, (animated) geometry from a virtual world... We produce as output pictures and videos.

These pictures will be viewed by humans, and we consider this fact as an important point of our research strategy, as it provides the benchmarks for evaluating our results: the pictures and animations produced must be able to convey the message to the viewer. The actual message depends on the specific application: data visualization, exploring virtual worlds, designing paintings and drawings... Our vision is that all these applications share common research problems: ensuring that the important features are perceived, avoiding cluttering or aliasing, efficient internal data representation, etc.

Computer Graphics, and especially Maverick is at the crossroad between fundamental research and industrial applications. We are both looking at the constraints and needs of applicative users and targeting long term research issues such as sampling and filtering.

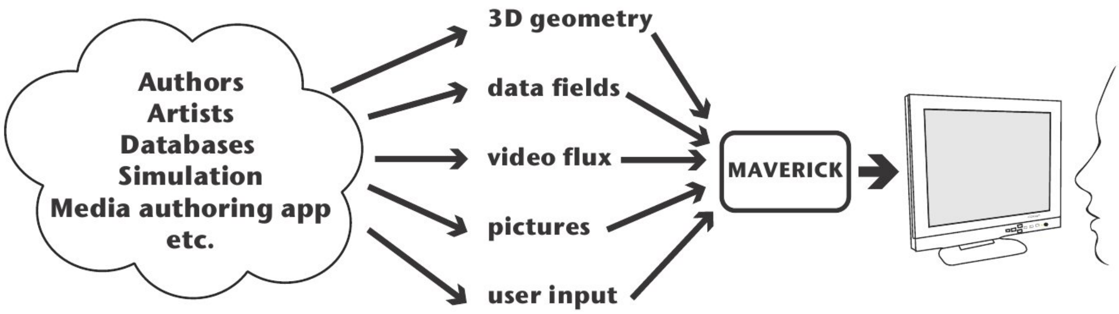

Figure 1. Position of the Maverick research team inside the graphics pipeline.

The oject-team aims at producing representations and algorithms for efficient, high-quality computer generation of pictures and animations through the study of four *Research problems*:

- *Computer Visualization*, where we take as input a large localized dataset and represent it in a way that will let an observer understand its key properties,
- *Expressive Rendering*, where we create an artistic representation of a virtual world,
- *Illumination Simulation*, where our focus is modelling the interaction of light with the objects in the scene.
- *Complex Scenes*, where our focus is rendering and modelling highly complex scenes.

The heart of *understanding* what makes a picture useful, powerful and interesting for the user, and designing algorithms to create these pictures.

We will address these research problems through three interconnected approaches:

- working on the *impact* of pictures, by conducting perceptual studies, measuring and removing artefacts and discontinuities, evaluating the user response to pictures and algorithms,
- developing *representations* for data, through abstraction, stylization and simplification,
- developing new methods for *predicting* the properties of a picture (*e.g.* frequency content, variations) and adapting our image-generation algorithm to these properties.

A fundamental element of the oject-team is that the research problems and the scientific approaches are all cross-connected. Research on the *impact* of pictures is of interest in three different research problems: *Computer Visualization*, *Expressive rendering* and *Illumination Simulation*. Similarly, our research on *Illumination simulation* will gatehr contributions from all three scientific approaches: impact, representations and prediction.

2.2. International Initiatives

2.2.1. Visits of International Scientists

- Professor Charles Hansen has started in November 2011 a visit of six month in the Maverick team. His six-months visit is funded by the University of Grenoble. Charles D. Hansen received a BS in computer science from Memphis State University in 1981 and a PhD in computer science from the University of Utah in 1987. He is a professor of computer science at the University of Utah an associate director of the SCI Institute. From 1989 to 1997, he was a Technical Staff Member in the Advanced Computing Laboratory (ACL) located at Los Alamos National Laboratory, where he formed and directed the visualization efforts in the ACL. He was a Bourse de Chateaubriand PostDoc Fellow at Inria, Rocquencourt France, in 1987 and 1988. His research interests include large-scale scientific visualization and computer graphics.
- Pascal Grosset visited from May to July 2012, funded by Inria internship (REUSSI). He worked on a psychometric experiment in order to evaluate the benefit of depth of field to improve depth perception in direct volumetric rendering. His work has been accepted for publication at IEEE Pacific Visualization [15].

2.3. Highlights of the Year

BEST PAPER AWARD :
[16] **Representing Appearance and Pre-filtering Subpixel Data in Sparse Voxel Octrees in High Performance Graphics**. E. HEITZ, F. NEYRET.

3. Scientific Foundations

3.1. Introduction

The Maverick project-team aims at producing representations and algorithms for efficient, high-quality computer generation of pictures and animations through the study of four **research problems**:

- *Computer Visualization* where we take as input a large localized dataset and represent it in a way that will let an observer understand its key properties. Visualization can be used for data analysis, for the results of a simulation, for medical imaging data...
- *Expressive Rendering*, where we create an artistic representation of a virtual world. Expressive rendering corresponds to the generation of drawings or paintings of a virtual scene, but also to some areas of computational photography, where the picture is simplified in specific areas to focus the attention.
- *Illumination Simulation*, where we model the interaction of light with the objects in the scene, resulting in a photorealistic picture of the scene. Research include improving the quality and photorealism of pictures, including more complex effects such as depth-of-field or motion-blur. We are also working on accelerating the computations, both for real-time photorealistic rendering and offline, high-quality rendering.
- *Complex Scenes*, where we generate, manage, animate and render highly complex scenes, such as natural scenes with forests, rivers and oceans, but also large datasets for visualization. We are especially interested in interactive visualization of complex scenes, with all the associated challenges in terms of processing and memory bandwidth.

The fundamental research interest of Maverick is first, *understanding* what makes a picture useful, powerful and interesting for the user, and second *designing* algorithms to create and improve these pictures.

3.2. Research approaches

We will address these research problems through three interconnected research approaches:

3.2.1. Picture Impact

Our first research axis deals with the *impact* pictures have on the viewer, and how we can improve this impact. Our research here will target:

- *evaluating user response:* we need to evaluate how the viewers respond to the pictures and animations generated by our algorithms, through user studies, either asking the viewer about what he perceives in a picture or measuring how his body reacts (eye tracking, position tracking).
- *removing artefacts and discontinuities:* temporal and spatial discontinuities perturb viewer attention, distracting the viewer from the main message. These discontinuities occur during the picture creation process; finding and removing them is a difficult process.

3.2.2. Data Representation

The data we receive as input for picture generation is often unsuitable for interactive high-quality rendering: too many details, no spatial organisation... Similarly the pictures we produce or get as input for other algorithms can contain superfluous details.

One of our goals is to develop new data representations, adapted to our requirements for rendering. This includes fast access to the relevant information, but also access to the specific hierarchical level of information needed: we want to organize the data in hierarchical levels, pre-filter it so that sampling at a given level also gives information about the underlying levels. Our research for this axis include filtering, data abstraction, simplification and stylization.

The input data can be of any kind: geometric data, such as the model of an object, scientific data before visualization, pictures and photographs. It can be time-dependent or not; time-dependent data bring an additional level of challenge on the algorithm for fast updates.

3.2.3. Prediction and simulation

Our algorithms for generating pictures require computations: sampling, integration, simulation... These computations can be optimized if we already know the characteristics of the final picture. Our recent research has shown that it is possible to predict the local characteristics of a picture by studying the phenomena involved: the local complexity, the spatial variations, their direction...

Our goal is to develop new techniques for predicting the properties of a picture, and to adapt our image-generation algorithms to these properties, for example by sampling less in areas of low variation.

Our research problems and approaches are all cross-connected. Research on the *impact* of pictures is of interest in three different research problems: *Computer Visualization*, *Expressive rendering* and *Illumination Simulation*. Similarly, our research on *Illumination simulation* will use all three research approaches: impact, representations and prediction.

3.3. Cross-cutting research issues

Beyond the connections between our problems and research approaches, we are interested in several issues, which are present throughout all our research:

sampling is an ubiquitous process occurring in all our application domains, whether photorealistic rendering (*e.g.* photon mapping), expressive rendering (*e.g.* brush strokes), texturing, fluid simulation (Lagrangian methods), etc. When sampling and reconstructing a signal for picture generation, we have to ensure both coherence and homogeneity. By *coherence*, we mean not introducing spatial or temporal discontinuities in the reconstructed signal.. By *homogeneity*, we mean that samples should be placed regularly in space and time. For a time-dependent signal, these requirements are conflicting with each other, opening new areas of research.

filtering is another ubiquitous process, occuring in all our application domains, whether in realistic rendering (*e.g.* for integrating height fields, normals, material properties), expressive rendering (*e.g.* for simplifying strokes), textures (through non-linearity and discontinuities). It is especially relevant when we are replacing a signal or data with a lower resolution (for hierarchical representation); this involves filtering the data with a reconstruction kernel, representing the transition between levels.

performance and scalability are also a common requirement for all our applications. We want our algorithms to be usable, which implies that they can be used on large and complex scenes, placing a great importance on scalability. For some applications, we target interactive and real-time applications, with an update frequency between 10 Hz and 120 Hz.

coherence and continuity in space and time is also a common requirement of realistic as well as expressive models which must be ensured despite contradictory requirements. We want to avoid flickering and aliasing.

animation: our input data is likely to be time-varying (*e.g.* animated geometry, physical simulation, time-dependent dataset). A common requirement for all our algorithms and data representation is that they must be compatible with animated data (fast updates for data structures, low latency algorithms...).

3.4. Methodology

Our research is guided by several methodological principles:

Experimentation: to find solutions and phenomenological models, we use experimentation, performing statistical measurements of how a system behaves. We then extract a model from the experimental data.

Validation: for each algorithm we develop, we look for experimental validation: measuring the behavior of the algorithm, how it scales, how it improves over the state-of-the-art... We also compare our algorithms to the exact solution. Validation is harder for some of our research domains, but it remains a key principle for us.

Reducing the complexity of the problem: the equations describing certain behaviors in image synthesis can have a large degree of complexity, precluding computations, especially in real time. This is true for physical simulation of fluids, tree growth, illumination simulation... We are looking for *emerging phenomena* and *phenomenological models* to describe them (see framed box "Emerging phenomena"). Using these, we simplify the theoretical models in a controlled way, to improve user interaction and accelerate the computations.

Transfering ideas from other domains: Computer Graphics is, by nature, at the interface of many research domains: physics for the behavior of light, applied mathematics for numerical simulation, biology, algorithmics... We import tools from all these domains, and keep looking for new tools and ideas.

Develop new fondamental tools: In situations where specific tools are required for a problem, we will proceed from a theoretical framework to develop them. These tools may in return have applications in other domains, and we are ready to disseminate them.

Collaborate with industrial partners: we have a long experiment of collaboration with industrial partners. These collaborations bring us new problems to solve, with short-term or medium-term transfert opportunities. When we cooperate with these partners, we have to find *what they need*, which can be very different from *what they want*, their expressed need.

4. Application Domains

4.1. Introduction

Maverick is part of the research theme "Interaction and Visualization" at Inria. This research theme has historically been very successful inside Inria. It nicely connects industrial applications with fundamental research using advanced mathematics, algorithmic and computer science, and it connects computer science with other sciences such as physics, biology, medicine, environment, psychophysiology.

We envision Maverick at this crossroad. We have several industrial partnerships, with companies making video games (Eden Games), special effects for motion pictures (WetaFX), planetarium (RSA Cosmos), graphical edition software (Adobe), tomography (Digisens) or visualizing simulated data (EDF). The constraints and needs of our partners motivate new problems for us to solve. At the same time, we are looking into fundamental research problems, such as analysis of light transport, human perception, filtering and sampling.

The fundamental research problems we target are not necessarily "long term research": the computer graphics industry is very dynamic and can adopt (and adapt) a research paper in a matter of months if it sees benefits in it. The research problems we describe as "fundamental" correspond to high-risk, high-benefit research problems. Solving these problems would result in a significant breakthrough for the whole domain of Computer Graphics, both in research and in industry.

4.2. 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.

4.3. 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.

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 Maverick' goals is to understand this dependence and automate the optimization.

4.4. 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

Maverick 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. PlantRad

Participant: Cyril Soler [contact].

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

5.3. High Quality Renderer

Participant: Cyril Soler [contact].

In the context of the European project RealReflect, the Maverick 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 Maverick, 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 at http://artis.imag.fr/~Cyril.Soler/HQR.

5.4. 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 at http://mobinet.inrialpes.fr 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.

5.5. Freestyle

Freestyle is a software for Non-Photorealistic Line Drawing rendering from 3D scenes (Figure 2). 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 [23], [24].

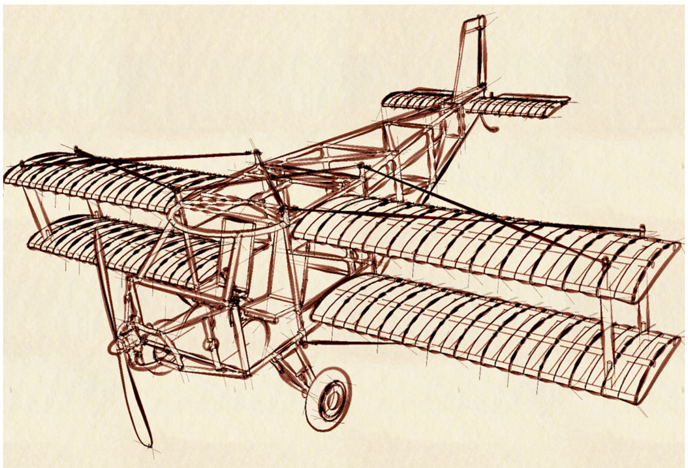

Figure 2. Stylized plane using Freestyle.

In 2008, Freestyle get a new life, completely outside Maverick or Inria: it was the basis of one of the 6 *Google Summer of Code* projects awarded to the *Blender Foundation* [1]! The goal of the project was to integrate Freestyle to the well known free 3D modeler *Blender*, as its standard NPR line-drawing renderer. Maxime Curioni (under the mentoring of Jean-Luc Peurière from the *Blender Foundation*), is currently making the integration. First beta versions are publicly available, and tested by enthusiasts around the web.

5.6. Diffusion Curves

Participant: Joëlle Thollot [contact].

[1] http://www.blender.org/

Figure 3. Diffusion curves freely downloadable demo.

We provide an implementation of the vector drawing tool described in the 2008 Diffusion Curves Siggraph paper (Figure 3) This prototype is composed of the Windows binary, along with the required shader programs (ie. in source code). The software is available for download at http://artis.imag.fr/Publications/2008/OBWBTS08 for free, for non-commercial research purposes.

5.7. 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 at http://artis.imag.fr/Software/VRender.

5.8. ProLand

Participants: Fabrice Neyret [contact], Eric Bruneton.

Now available at http://proland.inrialpes.fr/ in double licencing GPL/commercial.

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

5.9. GigaVoxel

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

Soon available at http://gigavoxels.inrialpes.fr/index.htm in double licencing GPL/commercial.

Gigavoxel is a software platform initiated from the PhD work of Cyril Crassin, and currently funded by the ANR CONTINT RTIGE (Figure 4). The goal of this platform is the real-time rendering of very large very detailed scenes. Performances permit showing details over deep zooms and walk through very crowdy scenes (which are rigid, for the moment). The principle is GPU ray-tracing of volumetric-encoded multiscale data with minimal just-in time generation of data (accounting visibility and needed resolution) kept in a cache on GPU. The representation eases the cheap management of soft shadows, depth of field, anti-aliasing and geometric LOD. Beside the representation, data management and base rendering algorithm themself, we also worked on realtime light transport, and on quality prefiltering of complex data. This work led to numerous publications ([22], [21], [20]). Several licences have been sold to companies. we also did a technical presentation of the GigaVoxels tool during Afig conference [17] in order to invit the community to use the tool.

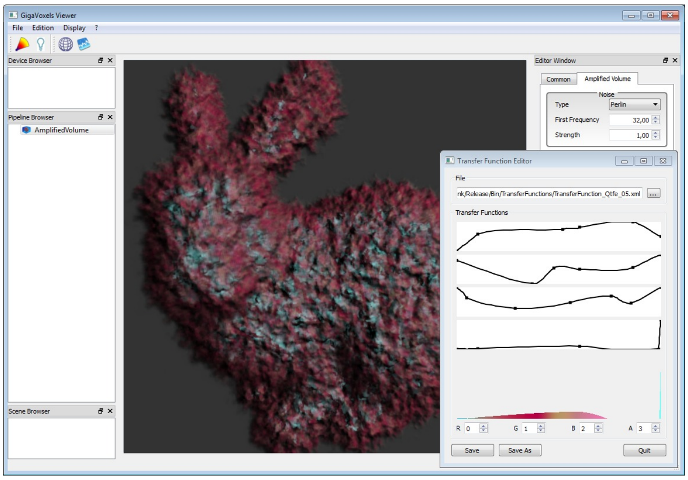

Figure 4. GigaVoxels freely downloadable demo.

6. New Results

6.1. Computer visualization

6.1.1. Immersive Virtual Environment for Visuo-Vestibular Therapy: Preliminary Results

Participants: Jean-Dominique Gascuel, Henri Payno, Sébastien Schmerber, Olivier Martin.

The sense of equilibrium aggregates several interacting cues. On patients with vestibular loss, vision plays a major role. In this study, the goal is to propose a new immersive therapy based on 3D opto-kinetic stimulation. We propose to demonstrate that 3D monoscopic optical flows are an efficient tool to stimulate adaptive postural adjustment. We developed an immersive therapeutic platform that enables to tune the balance task difficulty by managing optic flow speed and gaze anchoring (Figure 5). METHODOLOGY: the immersive sessions proposed to vestibular areflexic patients are composed of a repetition of dynamic optic flows, with varying speed and presence or not of a gaze anchor. The balance adjustments are recorded by a force plate, and quantified by the length of the center of pressure trajectory. RESULTS: Preliminary analysis shows that (i) Patients report a strong immersion felling in the motion flow, triggering more intense motor response to "fight against fall" than in standard opto-kinetic protocols; (ii) An ANOVA factorial design shows a significant effect of flow speed, session number and gaze anchor impact. CONCLUSION: This study shows that 3D immersive stimulation removes essential limits of traditional opto-kinetic stimulators (limited 2D motions and remaining fixed background cues). Moreover, the immersive optic flow stimulation is an efficient tool to induce balance adaptive reactions in vestibular patients. Hence, such a platform appears to be a powerful therapeutic tool for training and relearning of balance control processes.

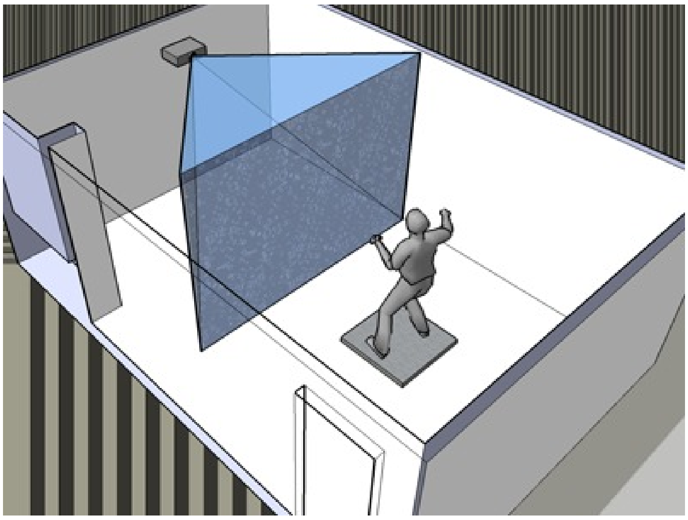

Figure 5. The immersive platform, installed in an available room of the hospital. The large retro projected screen is at 60 cm of the patient, covering most of its visual field. The patient is standing on a force plate, recording CoP.

6.1.2. Evaluation of Depth of Field for Depth Perception in DVR

Participants: Pascal Grosset, Mathias Schott, Georges-Pierre Bonneau, Hansen Charles.

we present a user study on the use of Depth of Field for depth perception in Direct Volume Rendering (Figure 6). Direct Volume Rendering with Phong shading and perspective projection is used as the baseline. Depth of Field is then added to see its impact on the correct perception of ordinal depth. Accuracy and response time are used as the metrics to evaluate the usefulness of Depth of Field. The on site user study has two parts: static and dynamic. Eye tracking is used to monitor the gaze of the subjects. From our results we see that though Depth of Field does not act as a proper depth cue in all conditions, it can be used to reinforce the perception of which feature is in front of the other. The best results (high accuracy & fast response time) for correct perception of ordinal depth is when the front feature (out of the users were to choose from) is in focus and perspective projection is used.

6.1.3. Volume Preserving FFD for Programmable Graphics Hardware

Participants: Stefanie Hahmann, Georges-Pierre Bonneau, Sébastien Barbier, Gershon Elber, Hans Hagen.

Free Form Deformation (FFD) is a well established technique for deforming arbitrary object shapes in space. Although more recent deformation techniques have been introduced, amongst them skeleton-based deformation and cage based deformation, the simple and versatile nature of FFD is a strong advantage, and

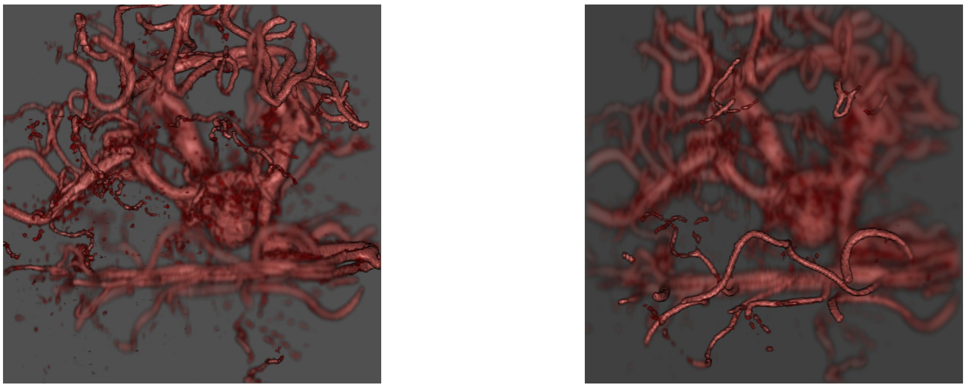

Figure 6. Aneurism. Depth of Field reinforces the perception of which feature is in front of the other.

justifies its presence in nowadays leading commercial geometric modeling and animation software systems. Since its introduction in the late 80's, many improvements have been proposed to the FFD paradigm, including control lattices of arbitrary topology, direct shape manipulation and GPU implementation. Several authors have addressed the problem of volume preserving FFD. These previous approaches either make use of expensive non-linear optimization techniques, or resort to first order approximation suitable only for small-scale deformations. In this paper we take advantage from the multi-linear nature of the volume constraint in order to derive a simple, exact and explicit solution to the problem of volume preserving FFD. Two variants of the algorithm are given, without and with direct shape manipulation. Moreover, the linearity of our solution enables to implement it efficiently on GPU (Figure 7).

6.1.4. Sharp feature preserving MLS surface reconstruction based on local feature line approximations

Participants: Christopher Weber, Stefanie Hahmann, Hans Hagen, Georges-Pierre Bonneau.

Sharp features in manufactured and designed objects require particular attention when reconstructing surfaces from unorganized scan point sets using moving least squares (MLS) fitting. It's an inherent property of MLS fitting that sharp features are smoothed out. Instead of searching for appropriate new fitting functions our approach computes a modified local point neighborhood so that a standard MLS fitting can be applied enhanced by sharp features reconstruction. We present a two-stage algorithm. In a pre-processing step sharp feature points are marked first. This algorithm is robust to noise since it is based on Gauss map clustering. In the main phase, the selected feature points are used to locally approximate the feature curve and to segment and enhance the local point neighborhood. The MLS projection thus leads to a piecewise smooth surface preserving all sharp features. The method is simple to implement and able to preserve line-type features as well as corner-type features during reconstruction (Figure 8).

6.2. Expressive rendering

6.2.1. Active Strokes: Coherent Line Stylization for Animated 3D Models

Participants: Pierre Bénard, Lu Jingwan, Forrester Cole, Adam Finkelstein, Joëlle Thollot.

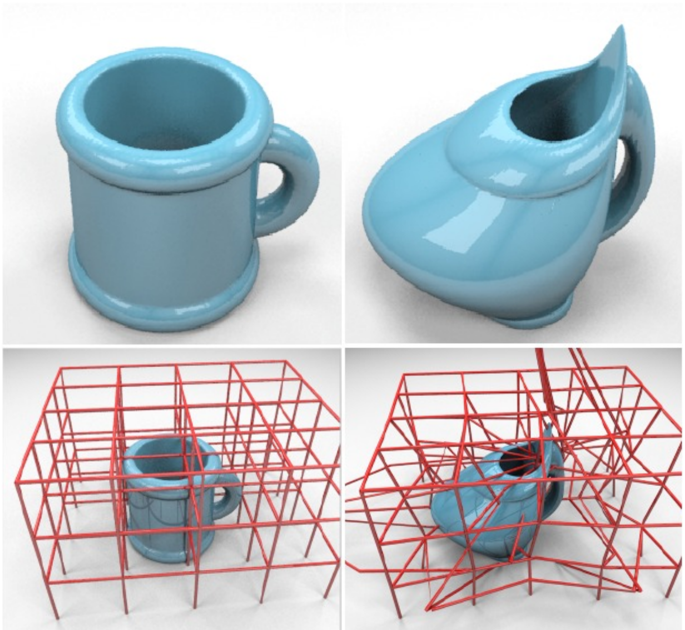

Figure 7. Sculptured cup with volume preservation.

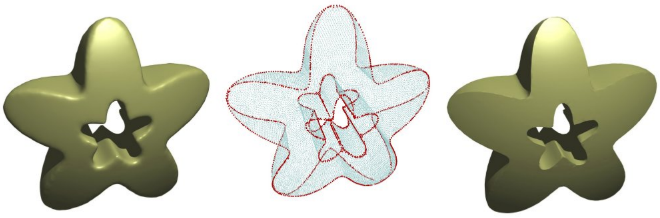

Figure 8. Left: standard MLS surface. Middle: feature point detection in point cloud. Right: sharp feature preserving MLS.

We present a method for creating coherently animated line drawings that include strong abstraction and stylization effects (Figure 9). These effects are achieved with active strokes: 2D contours that approximate and track the lines of an animated 3D scene. Active strokes perform two functions: they connect and smooth unorganized line samples, and they carry coherent parameterization to support stylized rendering. Line samples are approximated and tracked using active contours ("snakes") that automatically update their arrangment and topology to match the animation. Parameterization is maintained by brush paths that follow the snakes but are independent, permitting substantial shape abstraction without compromising fidelity in tracking. This approach renders complex models in a wide range of styles at interactive rates, making it suitable for applications like games and interactive illustrations.

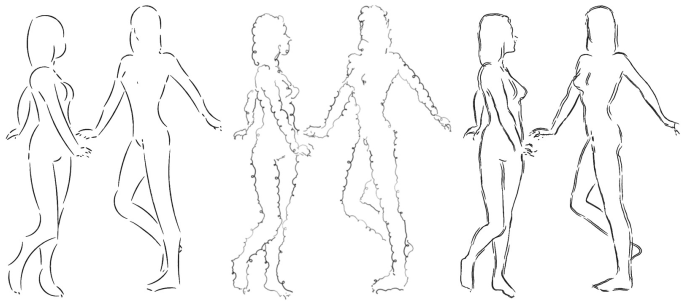

Figure 9. Stylization examples. Woman in two poses and three styles: arcs, loopy offsets, and overdrawn.

6.2.2. Temporally Coherent Video Stylization

Participants: Pierre Bénard, Joëlle Thollot, John Collomosse.

The transformation of video clips into stylized animations remains an active research topic in Computer Graphics. A key challenge is to reproduce the look of traditional artistic styles whilst minimizing distracting flickering and sliding artifacts; i.e. with temporal coherence. This chapter surveys the spectrum of available video stylization techniques, focusing on algorithms encouraging the temporally coherent placement of rendering marks, and discusses the trade-offs necessary to achieve coherence. We begin with flow-based adaptations of stroke based rendering (SBR) and texture advection capable of painting video. We then chart the development of the field, and its fusion with Computer Vision, to deliver coherent mid-level scene representations. These representations enable the rotoscoping of rendering marks on to temporally coherent video regions, enhancing the diversity and temporal coherence of stylization. In discussing coherence, we formalize the problem of temporal coherence in terms of three defined criteria, and compare and contrast video stylization using these.

6.3. Illumination simulation

6.3.1. Accurate fitting of measured reflectances using a Shifted Gamma micro-facet distribution

Participants: Mahdi M. Bagher, Cyril Soler, Nicolas Holzschuch.

Material models are essential to the production of photo-realistic images. Measured BRDFs provide accurate representation with complex visual appearance, but have larger storage cost. Analytical BRDFs such as Cook- Torrance provide a compact representation but fail to represent the effects we observe with measured appearance. Accurately fitting an analytical BRDF to measured data remains a challenging problem. In this paper we introduce the SGD micro-facet distribution for Cook-Torrance BRDF. This distribution accurately models the behavior of most materials. As a consequence, we accurately represent all measured BRDFs using a single lobe. Our fitting procedure is stable and robust, and does not require manual tweaking of the parameters (Figure 10).

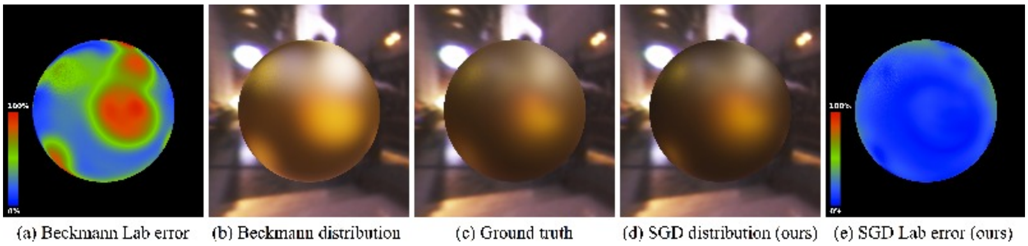

Figure 10. fitting of measured reflectances: comparison between ground truth and our approach.

6.3.2. Interactive rendering of acquired materials on dynamic geometry using bandwidth prediction

Participants: Mahdi M. Bagher, Cyril Soler, Kartic Subr, Laurent Belcour, Nicolas Holzschuch.

Shading complex materials such as acquired reflectances in multi-light environments is computationally expensive. Estimating the shading integral involves sampling the incident illumination independently at several pixels. The number of samples required for this integration varies across the image, depending on an intricate combination of several factors. Adaptively distributing computational budget across the pixels for shading is therefore a challenging problem. In this paper we depict complex materials such as acquired reflectances, interactively, without any precomputation based on geometry. We first estimate the approximate spatial and angular variation in the local light field arriving at each pixel. This *local bandwidth* accounts for combinations of a variety of factors: the reflectance of the object projecting to the pixel, the nature of the illumination, the local geometry and the camera position relative to the geometry and lighting. We then exploit this bandwidth information to adaptively sample for reconstruction and integration. For example, fewer pixels per area are shaded for pixels projecting onto diffuse objects, and fewer samples are used for integrating illumination incident on specular objects (Figure 11).

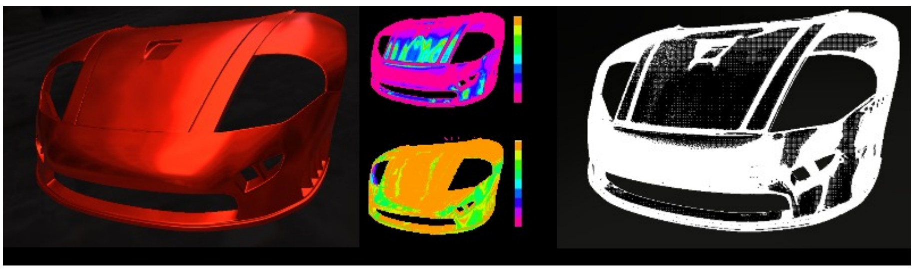

Figure 11. Interactive rendering of aquired materials. Center: predicted bandwidth and variance. Right: sample points where we compute illumination. Left: rendered result.

6.3.3. Real-Time Rendering of Rough Refraction

Participants: Charles De Rousiers, Adrien Bousseau, Kartic Subr, Nicolas Holzschuch, Ravi Ramamoorthi.

We present an algorithm to render objects made of transparent materials with rough surfaces in real-time, under all-frequency distant illumination (Figure 12). Rough surfaces cause wide scattering as light enters and exits objects, which significantly complicates the rendering of such materials. We present two contributions to approximate the successive scattering events at interfaces, due to rough refraction: First, an approximation of the Bidirectional Transmittance Distribution Function (BTDF), using spherical Gaussians, suitable for real-time estimation of environment lighting using pre-convolution; second, a combination of cone tracing and macro-geometry filtering to efficiently integrate the scattered rays at the exiting interface of the object. We demonstrate the quality of our approximation by comparison against stochastic ray-tracing. Furthermore we propose two extensions to our method for supporting spatially varying roughness on object surfaces and local lighting for thin objects.

(a) Ground truth (b) Our method

Figure 12. Real-Time Rendering of Rough Refraction

6.3.4. Multiple-scattering and double-scattering effects in translucent materials

Participants: Jean-Dominique Gascuel, Nicolas Holzschuch.

Some materials, such as coffee, milk or marble, have a soft translucent aspect because of sub-surface scattering: light enters them, is scattered several times inside before leaving in a different place. A full representation of sub-surface scattering effects in illumination simulation is computationally expensive. The main difficulty comes from multiple scattering events: the high number of events increases the incertainty on the result, forcing us to allocate more time for the computations. In this paper, we show that there is a strong correlation between the surface effects of multiple scattering inside the material and the effects after just two scatter events. This knowledge will help for accelerating multiple scattering effects.We also provide a model for fast computation of double-scattering events, using a precomputed density function we store in a compact way (Figure 13).

6.3.5. Frequency analysis of participating media

Participants: Laurent Belcour, Cyril Soler, Kavita Bala.

Computing global illumination in participating media is frustratingly expensive: while the computation itself is long and complicated, the result involve very smooth regions of illumination. This motivates an a priori approach to find out how fast the resulting image will vary in space (i.e. it’s spatial frequency) to adapt computation effort to reach the maximal efficiency. For this we are extending the theory of Fourier Analysis of

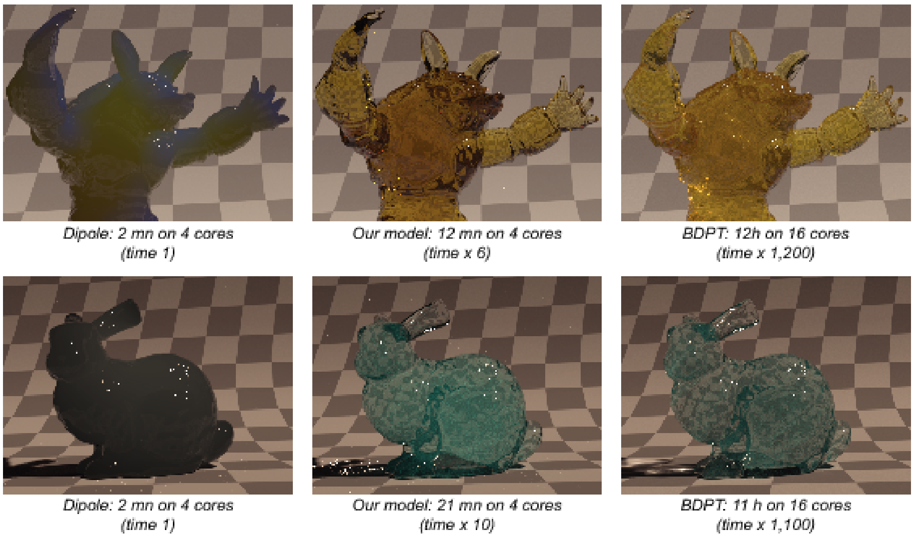

Figure 13. Multiple-scattering and double-scattering effects in translucent materials

light transport to participating media. Our work builds on the covariance analysis of light transport developed by Laurent Belcour in his PhD Thesis. It offers the possibility to drastically accelerate the algorithms involved in the computation of the illumination in scenes with participating media (Figure 14).

6.4. Complex scenes

6.4.1. A Survey of Non-linear Pre-filtering Methods for Efficient and Accurate Surface Shading

Participants: Eric Bruneton, Fabrice Neyret.

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

6.4.2. Real-time Realistic Rendering and Lighting of Forests

Participants: Eric Bruneton, Fabrice Neyret.

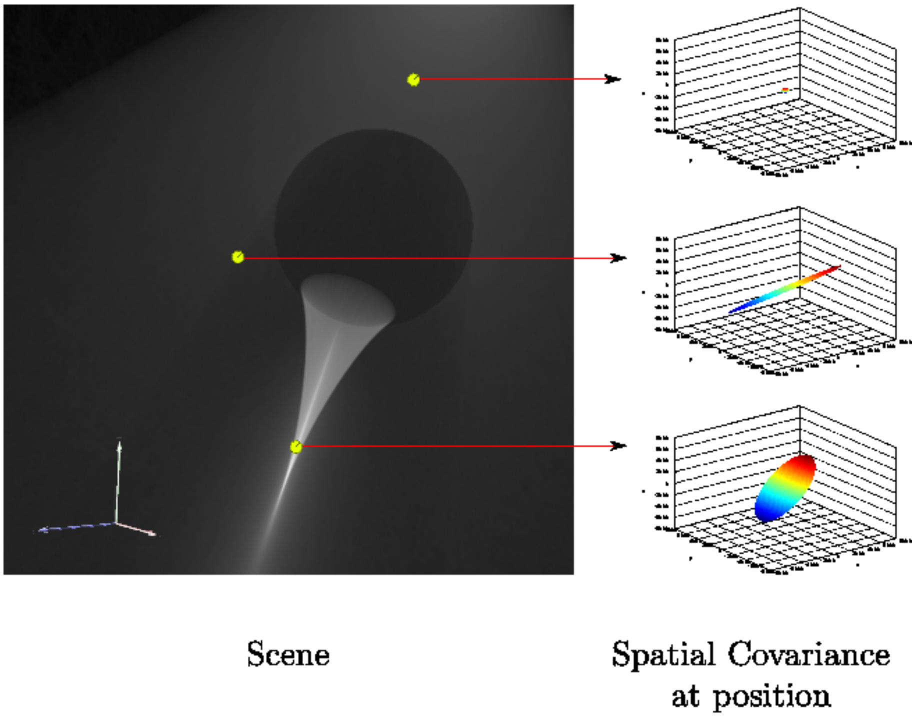

Figure 14. A glass sphere castinc a volumetric caustic in participating media with multiple scattering. We can predict the covariance of the spectrum of the illumination locally everywhere in the volume so as to adapt the computation effort.

Realistic real-time rendering and lighting of forests is an important aspect for simulators and video games. This is a difficult problem, due to the massive amount of geometry: aerial forest views display millions of trees on a wide range of distances, from the camera to the horizon. Light interactions, whose effects are visible at all scales, are also a problem: sun and sky dome contributions, shadows between trees, inside trees, on the ground, and view-light masking correlations. In this paper we present a method to render very large forest scenes in realtime, with realistic lighting at all scales, and without popping nor aliasing (Figure 15). Our method is based on two new forest representations, z-fields and shader-maps, with a seamless transition between them. Our first model builds on light fields and height fields to represent and render the nearest trees individually, accounting for all lighting effects. Our second model is a location, view and light dependent shader mapped on the terrain, accounting for the cumulated subpixel effects. Qualitative comparisons with photos show that our method produces realistic results.

Figure 15. Some real-time results obtained with our method, showing large forest scenes with a wide range of view distances, various tree densities and lighting conditions.

6.4.3. Representing Appearance and Pre-filtering Subpixel Data in Sparse Voxel Octrees

Participants: Eric Heitz, Fabrice Neyret.

Sparse Voxel Octrees (SVOs) represent efficiently complex geometry on current GPUs. Despite the fact that LoDs come naturally with octrees, interpolating and filtering SVOs are still issues in current approaches. In this paper, we propose a representation for the appearance of a detailed surface with associated attributes stored within a voxel octree. We store macro- and micro-descriptors of the surface shape and associated attributes in each voxel. We represent the surface macroscopically with a signed distance field and we encode subvoxel microdetails with Gaussian descriptors of the surface and attributes within the voxel. Our voxels form a continuous field interpolated through space and scales, through which we cast conic rays. Within the ray marching steps, we compute the occlusion distribution produced by the macro-surface inside a pixel footprint, we use the microdescriptors to reconstruct light- and view-dependent shading, and we combine fragments in an A-buffer way. Our representation efficiently accounts for various subpixel effects. It can be continuously interpolated and filtered, it is scalable, and it allows for efficient depth-of-field. We illustrate the quality of these various effects by displaying surfaces at different scales, and we show that the timings per pixel are scale-independent (Figure 16).

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. ANR BLANC: ALTA

Participants: Nicolas Holzschuch, Cyril Soler.

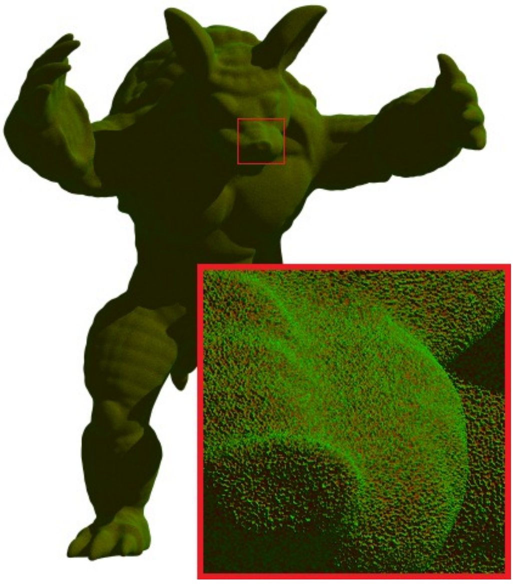

Figure 16. Our method allows for correct filtering of color variations, like anti-aliasing demonstrated here.

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

7.1.2. 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, obtained by Eric Bruneton) 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.

7.1.3. ANR CONTINT: RTIGE

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

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

7.1.4. ANR COSINUS: ROMMA

Participants: Georges-Pierre Bonneau, François Jourdes.

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

7.1.5. ANR CONTINT: MAPSTYLE

Participants: Joëlle Thollot, Hugo Loi.

The MAPSTYLE project aims at exploring the possibilities offered by cartography and expressive rendering to propose original and new cartographic representations. Through this project, we target two types of needs. On the one hand, mapping agencies produce series paper maps with some renderings that are still derived from drawings made by hand 50 years ago: for example, rocky areas in the series TOP25 (to 1/25000) of the French Institut Géographique National (IGN). The rendering of these rocky areas must be automated and its effectiveness retained to meet the requirements of hikers safety. On the other hand, Internet mapping tools allow any user to become a cartographer. However, they provide default styles that cannot be changed (GeoPortal, Google Maps) or they are editable but without any assistance or expertise (CloudMade). In such cases, as in the case of mobile applications, we identify the need to offer users means to design map styles more personalised and more attractive to meet their expectations (decision-making, recreation, etc.) and their tastes. The grant started on October 2012, for 48 months.

7.2. International Initiatives

7.2.1. Participation In International Programs

We had an internship funded by the REUSSI program. Pascal Grosset is PhD student at the university of Utah. He stayed in Maverick from May to July 2012.

7.3. International Research Visitors

7.3.1. Visits of International Scientists

Professor Charles Hansen has started in November 2011 a visit of six month in the Maverick team. His six-months visit is funded by the University of Grenoble. Charles D. Hansen received a BS in computer science from Memphis State University in 1981 and a PhD in computer science from the University of Utah in 1987. He is a professor of computer science at the University of Utah an associate director of the SCI Institute. From 1989 to 1997, he was a Technical Staff Member in the Advanced Computing Laboratory (ACL) located at Los Alamos National Laboratory, where he formed and directed the visualization efforts in the ACL. He was a Bourse de Chateaubriand PostDoc Fellow at Inria, Rocquencourt France, in 1987 and 1988. His research interests include large-scale scientific visualization and computer graphics.

7.3.1.1. Internships

Pascal Grosset visited from May to July 2012, funded by Inria internship (REUSSI). He worked on a psychometric experiment in order to evaluate the benefit of depth of field to improve depth perception in direct volumetric rendering. His work has been accepted for publication at IEEE Pacific Visualization [15].

7.3.2. Visits to International Teams

Eric Heitz is currently visiting the computer graphics group at the university of Montreal, funded by the explora'doc program from region Rhône-Alpes, from August 2012 to February 2013.

8. Dissemination

8.1. Scientific Animation

- Georges-Pierre Bonneau is member of the recruitment commity of associate professors at UJF.
- Georges-Pierre Bonneau is member of the IPCs of EUROVIS 2012.
- Joëlle Thollot is member of the IPCs of NPAR 2012.
- Joëlle Thollot is member of the IPCs of Computational Aesthetics 2012.
- Nicolas Holzschuch is program chair of the Eurographics Symposium on Rendering 2012,
- Nicolas Holzschuch is member of the "Commission d'évaluation" of Inria,
- Romain Vergne is member of the jury for the best paper at AFIG 2012.

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Joëlle Thollot and Georges-Pierre Bonneau are both full Professor of Computer Science. Romain Vergne is an associate professor in Computer Science. They teach general computer science topics at basic and intermediate levels, and advanced courses in computer graphics and visualization at the master levels. Nicolas Holzschuch teaches computer graphics at intermediate and advanced levels. Fabrice Neyret teached a course called "Science and Society" to master and doctorate students at the university of Rennes.

Joëlle Thollot, 200 hours a year, professor, ENSIMAG/Grenoble INP.

Georges-Pierre Bonneau, 200 hours a year, professor, Polytech/Grenoble UJF.

Romain Vergne, 200 hours a year, associate professor, IM2AG/Grenoble UJF.

Nicolas Holzschuch, 53 hours a year, DR2 Inria.

Fabrice Neyret, 3 hours a year, DR2 CNRS.

8.2.2. Supervision

PhD : Nassim Jibai, Multi-scale Feature-Preserving Smoothing of Images and Volumes on GPU, Université de Grenoble, May 2012, Nicolas Holzschuch, Jean-Philippe Farrugia.

PhD : Laurent Belcour, A Frequency Analysis of Light Transport: from Theory to Implementation, Université de Grenoble, November 2012, Nicolas Holzschuch, Cyril Soler.

PhD : Mahdi Bagher, Material appearance: photorealistic representation and rendering, Université de Grenoble, November 2012, Cyril Soler, Nicolas Holzschuch.

PhD : Alexandre Coninx, Visualisation interactive de grands volumes de données incertaines : pour une approche perceptive, Université de Grenoble, May 2012, Georges-Pierre Bonneau, Jacques Droulez.

PhD in progress : Eric Heitz, Représentations alternatives pour le traitement haute qualité efficace des scènes complexes, October 2010, Fabrice Neyret.

PhD in progress : Manuel Vennier, Modèles pour l'animation et le rendu temps réel d'oceans à des échelles multiples, December 2010, Fabrice Neyret, Joëlle Thollot.

PhD in progress : Léo Allemand-Giorgis, Visualisation de champs scalaires guidée par la topologie, October 2012, Georges-Pierre Bonneau, Stefanie Hahmann.

PhD in progress : Benoît Zupancic, acquisition of reflectance properties using compressive sensing, October 2012, Nicolas Holzschuch, Cyril Soler.

PhD in progress : Hugo Loi, Automatisation de la génération de textures vectorielles et application à la cartographie, October 2012, Joëlle Thollot, Thomas Hurtut.

PhD in progress : Alexandre Derouet-Jourdan, Courbes dynamiques : de la capture de formes géométriques à l'animation, September 2012, Florence Bertails-Descoubes, Joëlle Thollot.

8.2.3. Juries

- Georges-Pierre Bonneau was rapporteur at the PhD defense of Minh-Duc Huynh on July 2012, at the university of Pau.
- Joëlle Thollot was rapporteur at the PhD defense of Bert Buchholz on December 2012, at Paritech (Paris).
- Joëlle Thollot was rapporteur at the PhD defense of Jiazhou Chen on July 2012, at the university of Bordeaux 1.

8.3. Popularization

Fabrice Neyret made the following diffusions:

Articles about diffusion of critical thinking and scientific method (Observatoire Zététique, newsletter + website):

- "Analysis of a dr Labré's conference about 'alternative medicine': wrong obviousness and hidden contradictions."
- "Voices in my home ! Spirits or pareidolia ?"
- "Astrology lived from inside."

Actions for high-school students:

- MobiNet, free graphical programmable simulation software (http://mobinet.imag.fr)
- MobiNet class sessions: "maths & phys with meaning / how videogames and simulations are made ?". 8 high-school classes per year through INPG "engineering weeks" with regional funding.
- MobiNet class sessions: through MathC2+regional operation for high schools hosted by Inria.

Public debates and conferences:

- Jury + debate at Science-Po Grenoble about "virtuality and democracy"
- 3h in the Master transversal module about reseacher responsability (140 master & PhD students from all domains of Biology-Agronomy-Health at Rennes University)

Large public press and books:

- participation to the paper "History of Computer Graphics" in La Recherche
- "Sciences of 3D", book in preparation at Belin-PLS ed.

9. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] M. BAGHER. *Material appearance: photorealistic representation and rendering*, Université de Grenoble, November 2012.

[2] L. BELCOUR. *A Frequency Analysis of Light Transport: from Theory to Implementation*, Université de Grenoble, November 2012.

[3] A. CONINX. *Visualisation interactive de grands volumes de données incertaines : pour une approche perceptive*, Université de Grenoble, May 2012.

[4] N. JIBAI. *Multi-scale Feature-Preserving Smoothing of Images and Volumes on GPU*, Université de Grenoble, May 2012, http://tel.archives-ouvertes.fr/tel-00748064.

Articles in International Peer-Reviewed Journals

[5] M. BAGHER, C. SOLER, N. HOLZSCHUCH. *Accurate fitting of measured reflectances using a Shifted Gamma micro-facet distribution*, in "Computer Graphics Forum", June 2012, vol. 31, n^o 4 [*DOI :* 10.1111/J.1467-8659.2012.03147.X], http://hal.inria.fr/hal-00702304.

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[12] M. BAGHER, C. SOLER, K. SUBR, L. BELCOUR, N. HOLZSCHUCH. *Interactive rendering of acquired materials on dynamic geometry using bandwidth prediction*, in "I3D - ACM Siggraph Symposium on Interactive 3D Graphics and Games", Costa Mesa, United States, M. GARLAND, R. WANG (editors), ACM, March 2012, p. 127-134 [*DOI :* 10.1145/2159616.2159637], http://hal.inria.fr/hal-00652066.

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[16] *Best Paper*
E. HEITZ, F. NEYRET. *Representing Appearance and Pre-filtering Subpixel Data in Sparse Voxel Octrees*, in "High Performance Graphics", Paris, France, ACM, June 2012, Best Paper HPG 2012, http://hal.inria.fr/hal-00704461.

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