IN PARTNERSHIP WITH:
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Université Joseph Fourier (Grenoble)

Activity Report 2014

Project-Team MAVERICK

Models and Algorithms for Visualization and Rendering

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Interaction and visualization

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Project-Team MAVERICK

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

Creation of the Team: 2012 January 01, *updated into Project-Team:* 2014 January 01.

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2. Overall Objectives

2.1. Overall Objectives

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 as a research team in January 2012 and upgraded as a research project in January 2014. We deal 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.

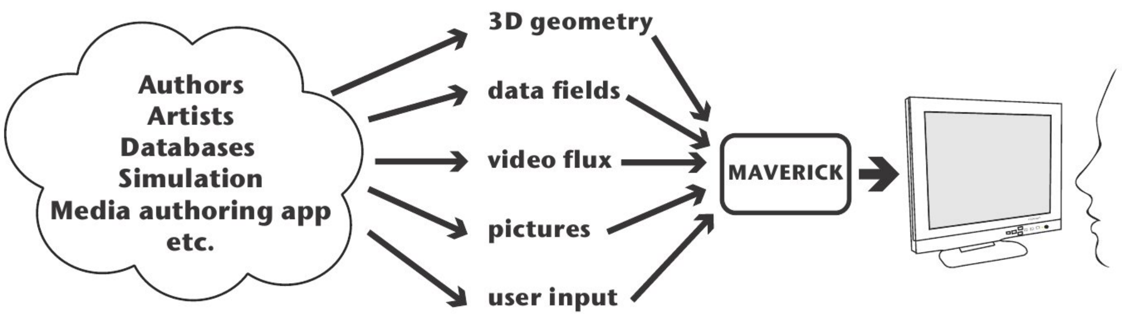


Figure 1. Position of the Maverick research team inside the graphics pipeline.

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 gather contributions from all three scientific approaches: impact, representations and prediction.

3. Research Program

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. New Software and Platforms

4.1. 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.

4.2. Gratin

Participant: Romain Vergne [contact].

Gratin is a node-based compositing software for creating, manipulating and animating 2D and 3D data. It uses an internal direct acyclic multi-graph and provides an intuitive user interface that allows to quickly design complex prototypes. Gratin has several properties that make it useful for researchers and students. (1) it works in real-time: everything is executed on the GPU, using OpenGL, GLSL and/or Cuda. (2) it is easily programmable: users can directly write GLSL scripts inside the interface, or create new C++ plugins that will be loaded as new nodes in the software. (3) all the parameters can be animated using keyframe curves to generate videos and demos. (4) the system allows to easily exchange nodes, group of nodes or full pipelines between people. In a research context, Gratin aims at facilitating the creation of prototypes, testing ideas and exchanging data. For students, Gratin can be used to show real-time demos/videos, or help learning how to program with the GPU. Gratin has already been used for creating new computer graphics tools but also for designing perceptual experiments. Most of the work published by R. Vergne was done with Gratin.

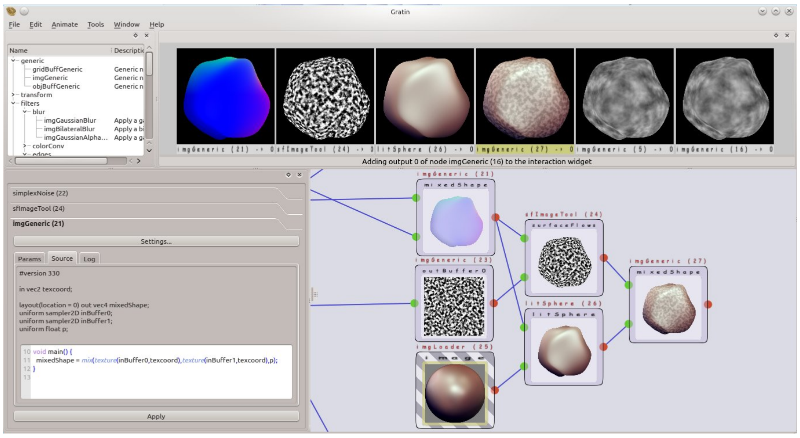


Figure 2. Gratin interface.

4.3. 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.

4.4. 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.

4.5. 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 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. A web version is currently under preliminary developpement.

4.6. Freestyle

Participant: Joëlle Thollot [contact].

Freestyle is a software for Non-Photorealistic Line Drawing rendering from 3D scenes (Figure 3). 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 [19], [20].

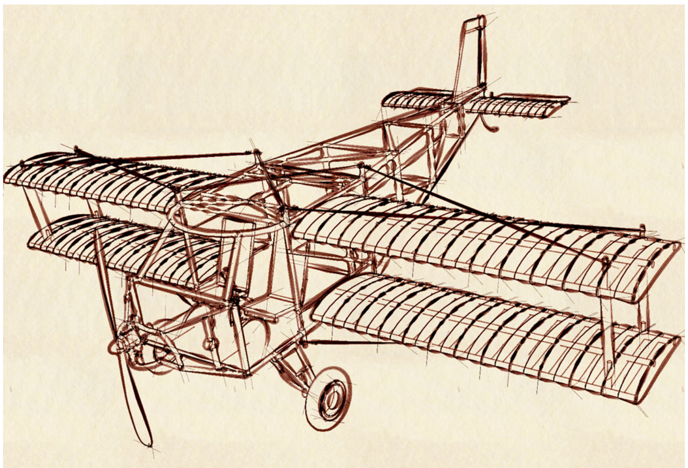


Figure 3. Stylized plane using Freestyle.

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.

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

4.7. Diffusion Curves

Participant: Joëlle Thollot [contact].

Figure 4. Diffusion curves freely downloadable demo.

We provide an implementation of the vector drawing tool described in our Diffusion Curves Siggraph paper [2] (Figure 4). 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.

4.8. 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.

4.9. 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.

4.10. GigaVoxels

Participants: Fabrice Neyret [contact], Prashant Goswami, Jérémy Sinoir, Cyril Crassin, Pascal Guehl, Paul Gannay, 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 5). The goal of this platform is the real-time quality rendering of very large and very detailed scenes which couldn't fit memory. Performances permit showing details over deep zooms and walk through very crowdy scenes (which are rigid, for the moment). The principle is to represent data on the GPU as a Sparse Voxel Octree which multiscale voxels bricks are produced on demand only when necessary and only at the required resolution, and kept in a LRU cache. User defined producer lays accross CPU and GPU and can load, transform, or procedurally create the data. Another user defined function is called to shade each voxel according to the user-defined voxel content, so that it is user choice to distribute the appearance-making at creation (for faster rendering) or on the fly (for storageless thin procedural details). The efficient rendering is done using a GPU differential cone-tracing using the scale corresponding to the 3D-MIPmapping LOD, allowing quality rendering with one single ray per pixel. Data is produced in case of cache miss, and thus only whenever visible (accounting for view frustum and occlusion). Soft-shadows and depth-of-field is easily obtained using larger cones, and are indeed cheaper than unblurred rendering. Beside the representation, data management and base rendering algorithm themself, we also worked on realtime light transport, and on quality prefiltering of complex data. Ongoing researches are addressing animation. GigaVoxels is currently used for the quality real-time exploration of the detailed galaxy in ANR RTIGE. This work led to several publications and several licences have been sold to companies.

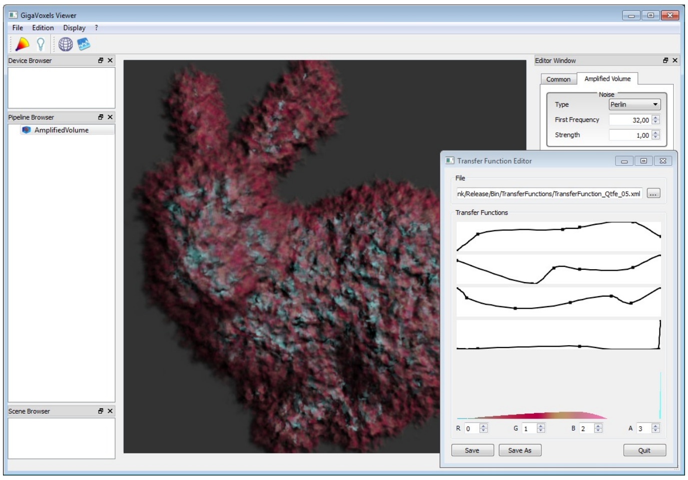


Figure 5. GigaVoxels freely downloadable demo.

5. New Results

5.1. Highlights of the Year

The impacting PhD work [3] of Eric Heitz on *appearance filtering* (see section 5.5.1) has received a very good reception in both academic and industrial world, including several "best paper" prizes in 2013 and 2014, invitation to participate to the Siggraph Course on Photorealistic Rendering [14], and statements of importance and/or integration by reference peoples and CG companies.

BEST PAPER AWARD :
[8] **Importance Sampling Microfacet-Based BSDFs using the Distribution of Visible Normals in Computer Graphics Forum**. E. HEITZ, E. D'EON.

5.2. Visual perception

5.2.1. The effects of surface gloss and roughness on color constancy for real 3-D objects

Participants: Jeoren J. M. Granzier, Romain Vergne [contact], Karl Gegenfurtner.

Color constancy denotes the phenomenon that the appearance of an object remains fairly stable under changes in illumination and background color. Most of what we know about color constancy comes from experiments using flat, matte surfaces placed on a single plane under diffuse illumination simulated on a computer monitor. Here we investigate whether material properties (glossiness and roughness) have an effect on color constancy for real objects. Subjects matched the color and brightness of cylinders (painted red, green, or blue) illuminated by simulated daylight (D65) or by a reddish light with a Munsell color book illuminated by a tungsten lamp. The cylinders were either glossy or matte and either smooth or rough. The object was placed in front of a black background or a colored checkerboard as shown in Figure 6. We found that color constancy was significantly higher for the glossy objects compared to the matte objects, and higher for the smooth objects compared to the rough objects. This was independent of the background. We conclude that material properties like glossiness and roughness can have significant effects on color constancy [7].

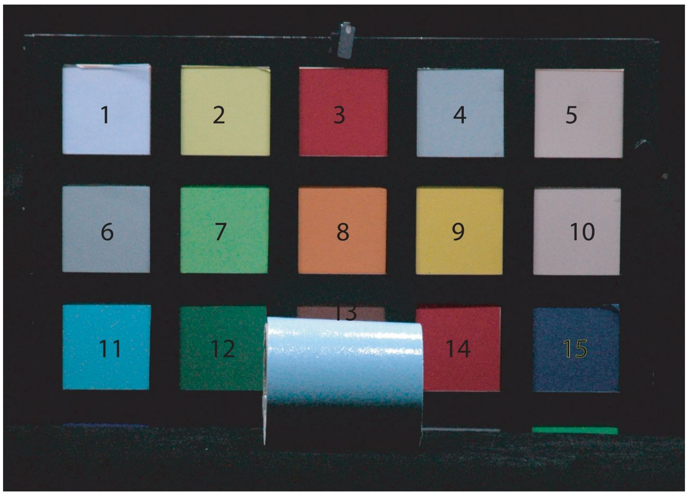


Figure 6. Color perception depends on material properties. This image represents one stimulus used in our experiment to compare the effect of glossiness on color constancy.

5.3. Visualization

Participants: Léo Allemand-Giorgis, Georges-Pierre Bonneau [contact].

In computer visualization we have worked on two topics: topology for visualization and perception for visualization.

In topology for visualization we have worked on scalar field vizualization methods taking into account the topology of the data. In [15] We have derived theoretical results on monotonic interpolation of scalar data. Our method enables to interpolate given topological data such as minima, maxima and saddle points at the corners of a rectangular domain without adding spurious extrema inside the function domain, as illustrated in Figure 7.

We have collaborated to a state of the art chapter on Uncertain Visualization [16], in which we described the evaluation of visualization methods based on visual perception.

Furthermore we have worked on two topics related to geometry for visualization. In [6] we introduce a method for interpolating a quad mesh using G1-continuous polynomial surfaces. We plan to use this method in the future for displaying isosurfaces of higher order data. In [12] we have published a method for reconstructing interfaces in highly complex assemblies, as illustrated in Figure 8. This method has been developed in order to visualize data arising from simulation of complex mechanical assemblies, within the ANR project ROMMA, closed in January 2014.

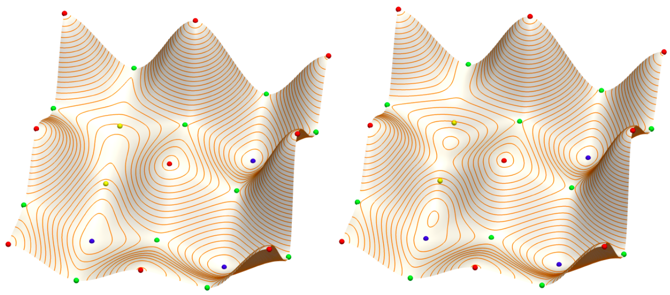


Figure 7. Local maxima (red), minima (blue), saddles (green) and regular (yellow) vertices are interpolated by a C1 piecewise cubic interpolant. Left: no unwanted local extrema exist in the interior of the cubic patches. Right: partial derivatives too large in size are chosen for the yelllow regular vertices implying that additional unwanted local extrema appear inside the cubic polynomial patches.

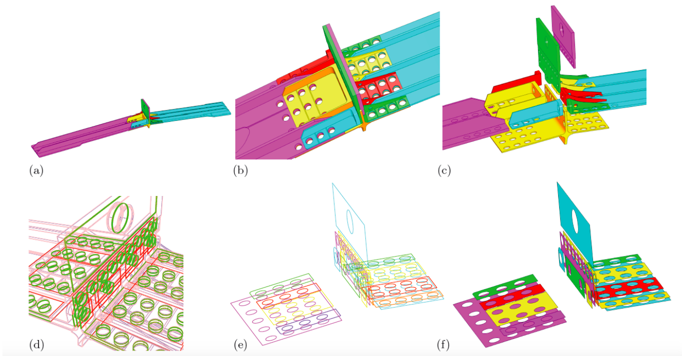


Figure 8. Aircraft part for assembling the wings with the body of an aircraft (model courtesy of EADS). (a,b) two views of the components, (c) exploded view, (d) ray casting results, (e) boundary reconstruction, (f) nal interfaces

5.4. Image creation and editing

5.4.1. Programmable 2D Arrangements for Element Texture Design

Participants: Hugo Loi, Thomas Hurtut, Romain Vergne, Joëlle Thollot [contact].

We introduce a programmable method for designing stationary 2D arrangements for element textures, namely textures made of small geometric elements. These textures are ubiquitous in numerous applications of computer-aided illustration. Previous methods, whether they be example-based or layout-based, lack control and can produce a limited range of possible arrangements. Our approach targets technical artists who will design an arrangement by writing a script. These scripts are using three types of operators: *partitioning operators* for defining the broad-scale organization of the arrangement, *mapping operators* for controlling the local organization of elements, and *merging operators* for mixing different arrangements. These operators are designed so as to guarantee a stationary result meaning that the produced arrangements will always be repetitive. We show (see Figure 10) that this simple set of operators is sufficient to reach a much broader variety of arrangements than previous methods. Editing the script leads to predictable changes in the synthesized arrangement, which allows an easy iterative design of complex structures. Finally, our operator set is extensible and can be adapted to application-dependent needs.

5.4.2. Color transfer guided by summary statistics

Participants: Benoît Arbelot, Romain Vergne [contact], Thomas Hurtut, Joëlle Thollot.

Modifying the colors of an image is an attractive way to edit its ambiance and mood. In practice, manually and directly tuning the color distribution of an image is challenging and tedious. Color transfer methods offer an intuitive alternative by automatically changing an image colors according to a target image. Existing transfer methods mostly rely on global matching processes to reshape and map the color histogram of the source image as close as possible to the target histogram. However, they offer no control over where the colors of the target will be transferred in the source image: they only tend to match colors that have similar intensities and chromaticities. This can lead to unexpected results, especially when some elements do not have the same colors in the two images, but share similar features. In this work, we propose to implicitly segment input images before transferring colors. Instead of relying on colors only, we use a summary of statistics to describe the underlying texture properties of each pixel. This provides a measure of pixel similarity which is then used to guide and ensure the transfer to be done between similar features (see Figure reffig:color for a preliminary result).

Source Target Tranfer

Figure 9. By transferring colors between statistically similar pixels, meaningful colors are transferred from the target to the source image.

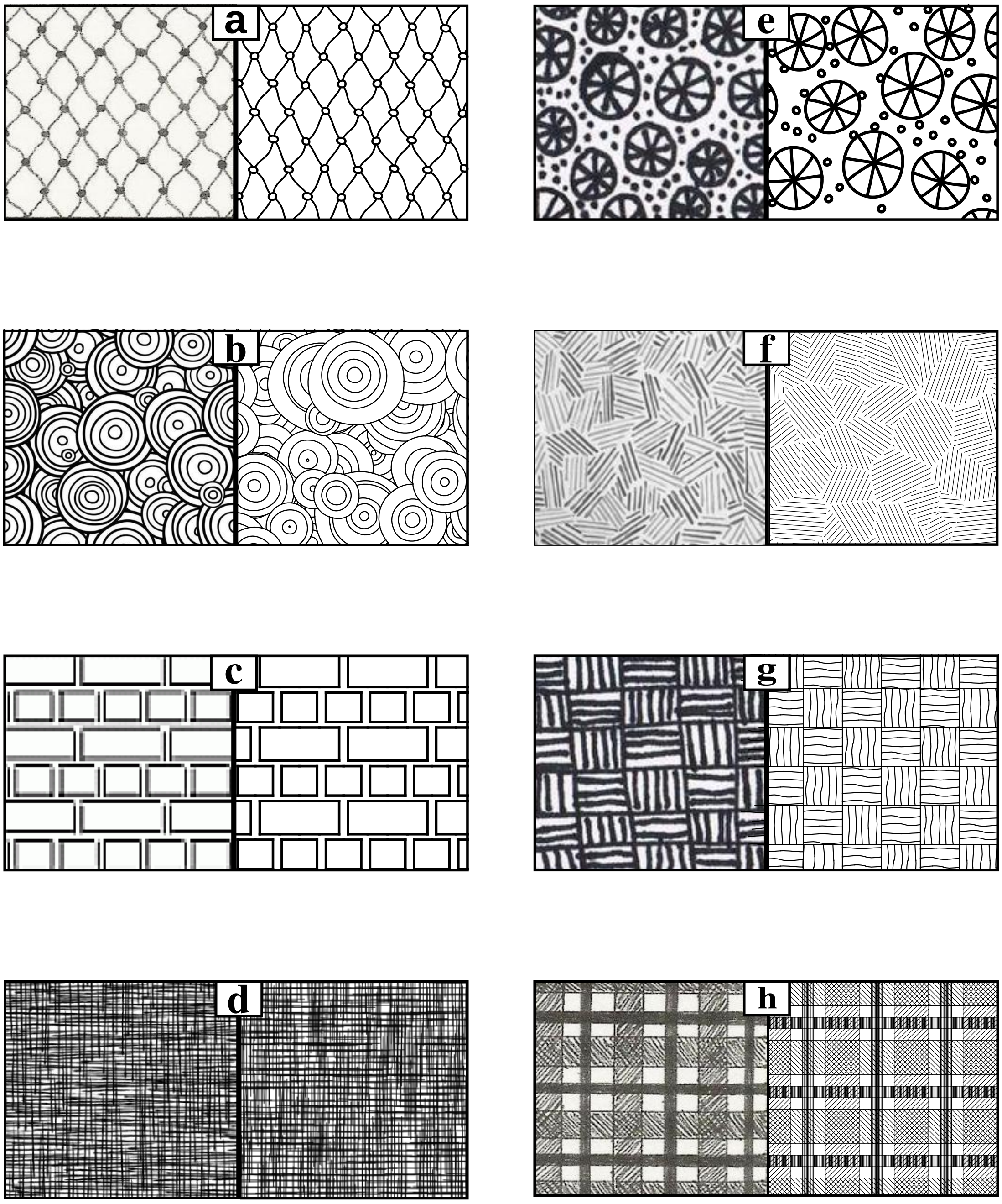


Figure 10. ***Element textures commonly used.*** *These textures can be found in professional art (d,g,h), casual art (a,e,f), technical productions such as Computer-Assisted Design illustration tools (c), and textile industry (b). For each example, we show a hand-drawn image (left), and our synthesized reproduction of its geometric arrangement (right).* ***(a,b,c)*** *Classic regular distributions with contact, overlap and no adjacency between elements respectively.* ***(d)*** *Overlap of two textures creating cross hatching.* ***(e)*** *Non overlapping combination of two textures.* ***(f,g,h)*** *Complex element textures with clusters of elements. — Image credit: (d,g,h) "Rendering in Pen and Ink: The Classic Book On Pen and Ink Techniques for Artists, Illustrators, Architects, and Designers" [21]; (a,e) Profusion Art [profusionart.blogspot.com]; (f) Hayes' Art Classes [hayesartclasses.blogspot.com]; (c) CompugraphX [www.compugraphx.com]; (b) 123Stitch [www.123stitch.com].*

5.5. Complex scenes

In order to render both efficiently and accurately ultra-detailed large scenes, this approach consists in developing representations and algorithms able to account compactly for the quantitative visual appearance of a regions of space projecting on screen at the size of a pixel.

5.5.1. Surfacic appearance pre-filtering

Participants: Eric Heitz, Fabrice Neyret [contact].

Here, we deal with complex surfaces represented by microfacets and material attributes.

Among the various correlations between material ingredients forming the BRDF, we published an extended version of the work on correlation between surface attribute (like color) and visibility [10], and Eric published an comprehensive interpretation of the microfacet model in a journal in the field of physics [9]. He also adapted his microfacet approach to the efficient BRDF sampling for path tracing – published in EGSR/CGF [8] –, see Figure 11, and he was invited to participate to the prestigious Siggraph Course "Physically Based Shading in Theory and Practice" [14]. This work is now implemented in various professional and standard software and thus settled a new standard. Eric defended his PhD on September, 26 2014 [3]

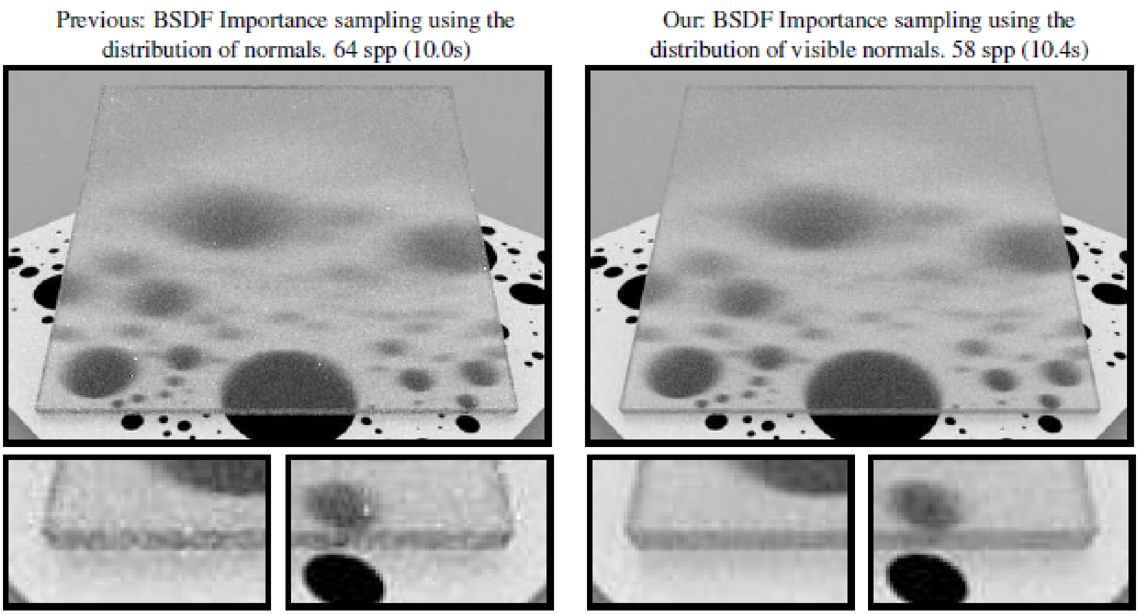


Figure 11. A dielectric glass plate (n = 1.5) with anisotropic GGX roughness (ax = 0.05, ay = 0.4) on all faces (with the Smith masking function). For a similar sample budget and the same render time, our method (right) significantly reduces the variance and converges faster than the common technique used in previous work (left).

5.5.2. Volumetric appearance pre-filtering

Participants: Guillaume Loubet, Fabrice Neyret [contact].

Here, we deal with complex density distributions. The first target is galactic material in the scope of the veRTIGE / Galaxy ANR project, but the long term goal is more general since at long distance complex surfaces or scattered objects can more efficiently be represented as volumetric distributions.

The usual hypothesis in CG is that volumes are homogeneous distribution of matter. But star and (dark) dust distributions are fractal, not homogeneous. This breaks all the existing equations accounting for large scale opacity and lighting of volumes of such material.

first, we developed a new procedural noise able to easily mimic such fractal distributions according to astrophysical models (see fig 12,a). Then we studied how to reproduce the same opacity (fig 12,b) and reflectivity (fig 12,c) for various level of details – this is still ongoing work.

Moreover, volumetric material is often concentrated into bodies, with a boundary delimited by a density jump or gradient. We studied the macroscopic light behavior in such configurations (fig 12,d).

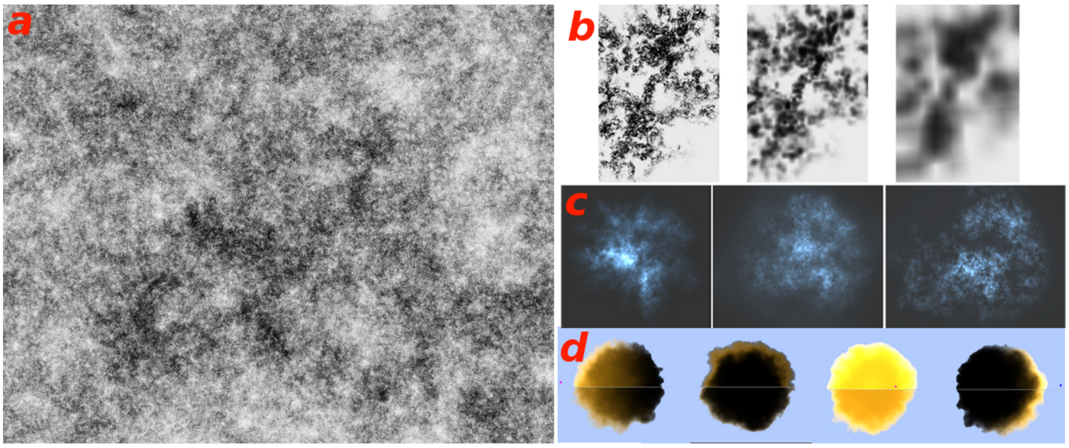


Figure 12. a: Our new fractal procedural noise. b: Multiscale opacity. c: Multiscale reflectance. d: Light reflection at volumetric bodies boundary with gradient (top) or jump (bottom) density distribution, with different light direction (left to right).

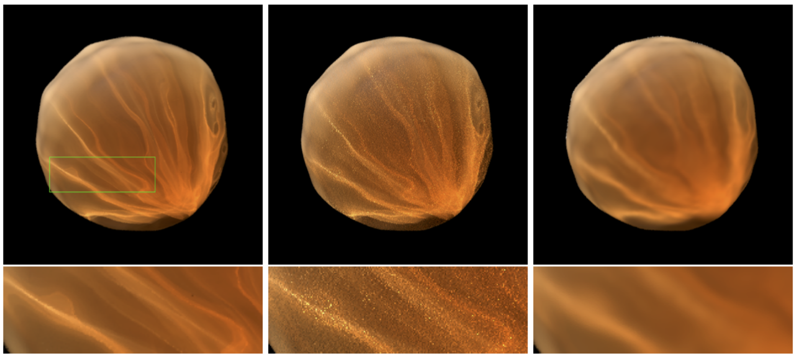
5.6. Realistic rendering

Note that Cyril Soler defended his HDR "*Models and Analyses for Image Synthesis*", Université Joseph-Fourier, on June 2014.

5.6.1. Single Scattering in participating media with refractive boundaries

Participant: Nicolas Holzschuch [contact].

Volume caustics are high-frequency effects appearing in participating media with low opacity, when refractive interfaces are focusing the light rays (see Figure 13). Refractions make them hard to compute, since screen locality does not correlate with spatial locality in the medium. We have developed a new method for accurate computation of single scattering effects in a participating media enclosed by refractive interfaces. Our algorithm is based on the observation that although radiance along each camera ray is irregular, contributions from individual triangles are smooth. Our method gives more accurate results than existing methods, faster. It uses minimal information and requires no precomputation or additional data structures. This paper was accepted for publication at Computer Graphics Forum [11].



(a) Our algorithm (169 s) **(b)** Point samples [WZHB09] (27 samples, 170 s) **(c)** Photon mapping (650 000 photons, 167 s)

Figure 13. Single scattering: comparison between our algorithm and existing methods (equal computation time) on a translucent sphere illuminated by a point light source from behind.

5.6.2. A Local Frequency Analysis of Light Scattering and Absorption

Participants: Laurent Belcour, Kavita Bala, Cyril Soler [contact].

We proposed a novel analysis of absorption and scattering of local light fields in the Fourier domain in the neighorhood of light paths. This analysis aims at predicting the changes over the distribution of light energy, so as to allow efficient sampling and integration methods of diffused light in participating media. Our analysis explains that absorbtion increases frequency since it acts as a continuous visibility mask over the local light field, and that scattering lowers frequencies as it operates a low pass convolution filter in the directional domain. In order to combine this analysis with our previous work on covariance tracing—and therefore use it to improve existing algorithms for path tracing in participating media—we derived new sampling metrics all based on a common prediction of the 3D covariance of the fluence in the volume. We demonstrate indeed that the covariance of the fluence can efficiently be computed by combining the 4D covariance matrices of light fields in the neighborhood of light paths, and that it can be used to compute effective metrics (1) for the variance of energy collected along camera rays, (2) for determining the shape and size of reconstruction kernels in screen space, and (3) for drastically improving the convergence of density estimation methods. For the later, we propose an improvement of the method of Progressive Photon Beams. This work has been published in ACM Transactions on Graphics and presented at Siggraph'2014 in Vancouver [5].

6. Partnerships and Cooperations

6.1. National Initiatives

6.1.1. ANR BLANC: ALTA

Participants: Nicolas Holzschuch [contact], Cyril Soler.

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.

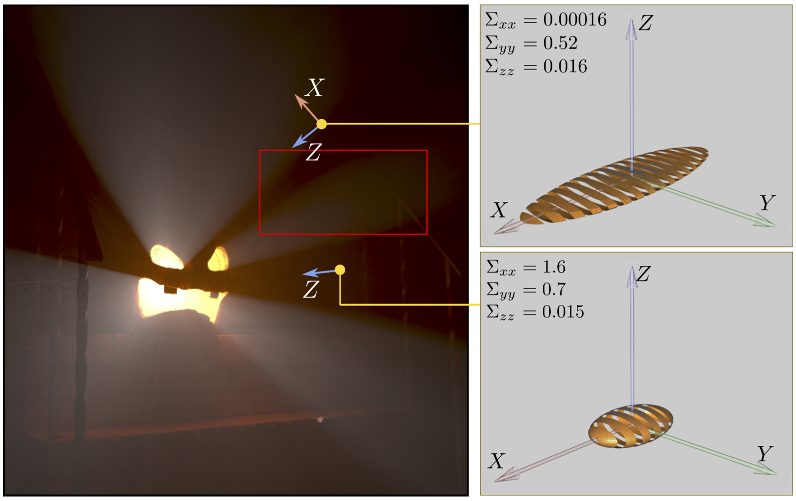


Figure 14. Predictions of the covariance of the Fourier spectrum of the fluence in the volume computed using our Fourier analysis of scattering and absorption.

6.1.2. ANR CONTINT: Galaxy/veRTIGE

Participants: Jean-Dominique Gascuel, Nicolas Holzschuch, Fabrice Neyret [contact].

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. The goal of this project is to simulate the quality multi-spectral real-time exploration of the Galaxy with Hubble-like images, based on simulation data, statistical data coming from observation, star catalogs, and procedural amplification for stars and dust clouds distributions. RSA-Cosmos aims at integrating the results in digital planetariums. The grant started in December 2010, for 48 months.

6.1.3. ANR COSINUS: ROMMA

Participants: Georges-Pierre Bonneau [contact], 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.

6.1.4. ANR CONTINT: MAPSTYLE

Participants: Joëlle Thollot [contact], 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.

6.2. International Initiatives

6.2.1. Inria International Partners

6.2.1.1. Informal International Partners

We have a continuing collaboration with Professor Kavita Bala, from Cornell University, USA, on the subject of global illumination and simulation of light scattering in participating media. Our work has been accepted at ACM transaction on graphics in 2014.

We currently have a very fruitful collaboration with Derek Nowrouzhezarai, from University of Montreal, Canada, dealing with isotropic filter decomposition in the spherical domain, based on zonal harmonic basis.

We also have frequent exchanges and on-going collaborations with Cyril Crassin from nVIDIA-Research.

6.3. International Research Visitors

6.3.1. Visits to International Teams

6.3.1.1. Research stays abroad

Fabrice Neyret has been visiting WETA Digital (New-Zeland) from July to August 2014.

7. Dissemination

7.1. Promoting Scientific Activities

7.1.1. Scientific events organisation

7.1.1.1. member of the organizing committee

- Georges-Pierre Bonneau: co-chair of the Industrial track of *Eurographics* 2014,
- Nicolas Holzschuch: co-chair of the Tutorial track of *Eurographics* 2014

7.1.2. Scientific events selection

7.1.2.1. member of the conference program committee

- Georges-Pierre Bonneau:
  - Workshop on *Visualization in Environmental Sciences* (EnvirVis) 2014.
- Nicolas Holzschuch:
  - *ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games* 2014 and 2015,
  - *Eurographics* 2015 ,
- Cyril Soler:
  - *Eurographics Symposium on Rendering* 2014,
  - *Eurographics* 2014,
  - *Pacific Graphics* 2014.
- Joëlle Thollot:
  - *Expressive* conference (merging of NPAR, Computational Aesthetics and SBIM) 2014.

7.1.2.2. reviewer

All the faculties and some of the PhD students are collectively reviewing for all the major journals and conferences and the domain, and beyond this perimeter.

7.1.3. Journal

7.1.3.1. reviewer

All the faculties and some of the PhD students are collectively reviewing for all the major journals and conferences and the domain, and beyond this perimeter.

7.2. Teaching - Supervision - Juries

7.2.1. 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 advanced courses in computer graphics at the Master level. In addition, Romain Vergne teached an advanced course on "perception & graphics" at the spring school of ôkhra (Roussillon).

7.2.2. Supervision

- PhD: Eric Heitz, *Représentations alternatives pour le traitement haute qualité efficace des scènes complexes*, Université de Grenoble, October 2014, Fabrice Neyret
- PhD in progress: Guillaume Loubet, *Représentations efficaces de l'apparence sous-pixel*, Université de Grenoble, October 2010, Fabrice Neyret
- PhD in progress : Léo Allemand-Giorgis, *Visualisation de champs scalaires guidée par la topologie*, October 2012, Georges-Pierre Bonneau, Stefanie Hahmann.
- PhD in progress : Aarohi Johal, *Algorithmes de génération automatique d'arbres de construction à partir de modèles géométriques CAO B-Rep*, September 2013, Jean-Claude Léon, Georges-Pierre Bonneau, thèse CIFRE EdR R&D.
- 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 : Benoit Arbelot, *Etudes statistiques de forme, de matériaux et d'environnement pour la manipulation de l'apparence*, October 2013, Joëlle Thollot, Romain Vergne.

7.2.3. Juries

- Joelle Thollot has been member of the jury for the PhD of Arnaud Emilien (Grenoble, 10/12/14)

7.3. Popularization

Every year, "MobiNet" (see section 4.5) classes are conducted with high school pupils of the large Grenoble area to practice initiation and intuition on Computer Science, Maths and Physics. Depending on the year, we have 2 to 4 groups in the scope of INP-Grenoble "Enginneering weeks", and 0 to 2 groups in the scope of Math-C2+ operations.

8. Bibliography

Major publications by the team in recent years

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Articles in International Peer-Reviewed Journals

[5] L. BELCOUR, K. BALA, C. SOLER. *A Local Frequency Analysis of Light Scattering and Absorption*, in "ACM Transactions on Graphics", August 2014, vol. 33, n^o 5, 17 p. , (presented at SIGGRAPH 2014), https://hal.inria.fr/hal-00957242

[6] G.-P. BONNEAU, S. HAHMANN. *Flexible G1 Interpolation of Quad Meshes*, in "Graphical Models", 2014, https://hal.inria.fr/hal-01064552

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E. HEITZ, E. D'EON. *Importance Sampling Microfacet-Based BSDFs using the Distribution of Visible Normals*, in "Computer Graphics Forum", July 2014, vol. 33, n^o 4, pp. 103-112 [*DOI :* 10.1111/CGF.12417], https://hal.inria.fr/hal-00996995.

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