INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team reves

Rendering and virtual environments with sound

Sophia Antipolis - Méditerranée

Theme : Interaction and Visualization

Activity Report

2010

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2. Overall Objectives

2.1. General Presentation

Images, often accompanied by sound effects, have become increasingly present in our everyday lives; this has resulted in greater needs for content creation. Despite the fact that many traditional means exist, such as photography, artistic graphic design, audio mixing, they typically still remain the reserve of the expert, and require significant investment in time and expertise. Our main interest is computer image and sound synthesis, with an emphasis on automated methods. Our main goals include the simplification of the tasks required for the production of sound and images, as well as the development of new techniques for their generation.

The application domain is vast. It ranges from audiovisual production, which typically requires long, offline computation to obtain high quality results, all the way to real-time applications such as computer games or virtual reality, for which the main consideration is to guarantee 60 frames per second frame rates, or, in general the reduction of latency to user reaction. The process of generation of images and sound, generally called *rendering* is our primary interest; our second main interest are virtual environments (VE's) as well as augmented (AE's) or mixed environments (ME's), that is scenes containing both real objects (often digitized) as well as purely synthetic objects. We are interested in both the generation and the interaction with these environments. We use the term virtual environments for scenes with a certain degree of interactivity, potentially in a semi-immersive (stereo and tracking, workbench) or immersive (CAVE, RealityCenter) context.

2.2. Highlights

Nicolas Bonneel, Michiel van de Panne, Sylvain Lefebvre and George Drettakis were assigned the VMV 2010 Best Paper Award for their paper on "Proxy-Guided Texture Synthesis for Rendering Natural Scenes".

Adrien Bousseau joined the group as a junior researcher in October on a permanent position.

3. Scientific Foundations

3.1. Rendering

We consider plausible rendering to be a first promising research direction, both for images and for sound. Recent developments, such as point rendering, image-based modeling and rendering, and work on the simulation of aging indicate high potential for the development of techniques which render *plausible* rather than extremely accurate images. In particular, such approaches can result in more efficient renderings of very complex scenes (such as outdoors environments). This is true both for visual (image) and sound rendering. In the case of images, such techniques are naturally related to image- or point-based methods. It is important to note that these models are becoming more and more important in the context of network or heterogeneous rendering, where the traditional polygon-based approach is rapidly reaching its limits. Another research direction of interest is realistic rendering using simulation methods, both for images and sound. In some cases, research in these domains has reached a certain level of maturity, for example in the case of lighting and global illumination. For some of these domains, we investigate the possibility of technology transfer with appropriate partners. Nonetheless, certain aspects of these research domains, such as visibility or high-quality sound still have numerous and interesting remaining research challenges.

3.1.1. Plausible Rendering

3.1.1.1. Alternative representations for complex geometry

The key elements required to obtain visually rich simulations, are sufficient geometric detail, textures and lighting effects. A variety of algorithms exist to achieve these goals, for example displacement mapping, that is the displacement of a surface by a function or a series of functions, which are often generated stochastically. With such methods, it is possible to generate convincing representations of terrains or mountains, or of non-smooth objects such as rocks. Traditional approaches used to represent such objects require a very large number of polygons, resulting in slow rendering rates. Much more efficient rendering can be achieved by using point or image based rendering, where the number of elements used for display is view- or image resolution-dependent, resulting in a significant decrease in geometric complexity. Such approaches have very high potential. For example, if all object can be rendered by points, it could be possible to achieve much higher quality local illumination or shading, using more sophisticated and expensive algorithms, since geometric complexity will be reduced. Such novel techniques could lead to a complete replacement of polygon-based rendering for complex scenes. A number of significant technical challenges remain to achieve such a goal, including sampling techniques which adapt well to shading and shadowing algorithms, the development of algorithms and data structures which are both fast and compact, and which can allow interactive or real-time rendering. The type of rendering platforms used, varying from the high-performance graphics workstation all the way to the PDA or mobile phone, is an additional consideration in the development of these structures and algorithms. Such approaches are clearly a suitable choice for network rendering, for games or the modelling of certain natural object or phenomena (such as vegetation, e.g. Figure 1, or clouds). Other representations merit further research, such as image or video based rendering algorithms, or structures/algorithms such as the "render cache" [40], which we have developed in the past, or even volumetric methods. We will take into account considerations related to heterogeneous rendering platforms, network rendering, and the appropriate choices depending on bandwith or application. Point- or image-based representations can also lead to novel solutions for capturing and representing real objects. By combining real images, sampling techniques and borrowing techniques from other domains (e.g., computer vision, volumetric imaging, tomography etc.) we hope to develop representations of complex natural objects which will allow rapid rendering. Such approaches are closely related to texture synthesis and image-based modeling. We believe that such methods will not replace 3D (laser or range-finger) scans, but could be complementary, and represent a simpler and lower cost alternative for certain applications (architecture, archeology etc.). We are also investigating methods for adding "natural appearance" to synthetic objects. Such approaches include *weathering* or *aging* techniques, based on physical simulations [28], but also simpler methods such as accessibility maps [37]. The approaches we intend to investigate will attempt to both combine and simplify existing techniques, or develop novel approaches founded on generative models based on observation of the real world.

3.1.1.2. Plausible audio rendering

Similar to image rendering, plausible approaches can be designed for audio rendering. For instance, the complexity of rendering high order reflections of sound waves makes current geometrical approaches inappropriate. However, such high order reflections drive our auditory perception of "reverberation" in a virtual environment and are thus a key aspect of a plausible audio rendering approach. In complex environments, such as cities, with a high geometrical complexity, hundreds or thousands of pedestrians and vehicles, the acoustic field is extremely rich. Here again, current geometrical approaches cannot be used due to the overwhelming number of sound sources to process. We study approaches for statistical modeling of sound scenes to efficiently deal with such complex environments. We also study perceptual approaches to audio rendering which can result in high efficiency rendering algorithms while preserving visual-auditory consistency if required.

Figure 1. Plausible rendering of an outdoors scene containing points, lines and polygons [27], representing a scene with trees, grass and flowers. We can achieve 7-8 frames per second compared to tens of seconds per image using standard polygonal rendering.

3.1.2. High Quality Rendering Using Simulation

3.1.2.1. Non-diffuse lighting

A large body of global illumination research has concentrated on finite element methods for the simulation of the diffuse component and stochastic methods for the non-diffuse component. Mesh-based finite element approaches have a number of limitations, in terms of finding appropriate meshing strategies and form-factor calculations. Error analysis methodologies for finite element and stochastic methods have been very different in the past, and a unified approach would clearly be interesting. Efficient rendering, which is a major advantage of finite element approaches, remains an overall goal for all general global illumination research. For certain cases, stochastic methods can be efficient for all types of light transfers, in particular if we require a view-dependent solution. We are also interested both in *pure* stochastic methods, which do not use finite element techniques. Interesting future directions include filtering for improvement of final image quality as well as beam tracing type approaches [38] which have been recently developed for sound research.

3.1.2.2. *Visibility and Shadows*

Visibility calculations are central to all global illumination simulations, as well as for all rendering algorithms of images and sound. We have investigated various global visibility structures, and developed robust solutions for scenes typically used in computer graphics. Such analytical data structures [32], [31], [30] typically have robustness or memory consumption problems which make them difficult to apply to scenes of realistic size. Our solutions to date are based on general and flexible formalisms which describe all visibility event in terms of generators (vertices and edges); this approach has been published in the past [29]. Lazy evaluation, as well as hierarchical solutions, are clearly interesting avenues of research, although are probably quite application dependent.

3.1.2.3. *Radiosity*

For purely diffuse scenes, the radiosity algorithm remains one of the most well-adapted solutions. This area has reached a certain level of maturity, and many of the remaining problems are more technology-transfer oriented We are interested in interactive or real-time renderings of global illumination simulations for very complex scenes, the "cleanup" of input data, the use of application-dependent semantic information and mixed representations and their management. Hierarchical radiosity can also be applied to sound, and the ideas used in clustering methods for lighting can be applied to sound.

3.1.2.4. *High-quality audio rendering*

Our research on high quality audio rendering is focused on developing efficient algorithms for simulations of geometrical acoustics. It is necessary to develop techniques that can deal with complex scenes, introducing efficient algorithms and data structures (for instance, beam-trees [33] [38]), especially to model early reflections or diffractions from the objects in the environment. Validation of the algorithms is also a key aspect that is necessary in order to determine important acoustical phenomena, mandatory in order to obtain a high-quality result. Recent work by Nicolas Tsingos at Bell Labs [34] has shown that geometrical approaches can lead to high quality modeling of sound reflection and diffraction in a virtual environment (Figure 2). We will pursue this research further, for instance by dealing with more complex geometry (e.g., concert hall, entire building floors).

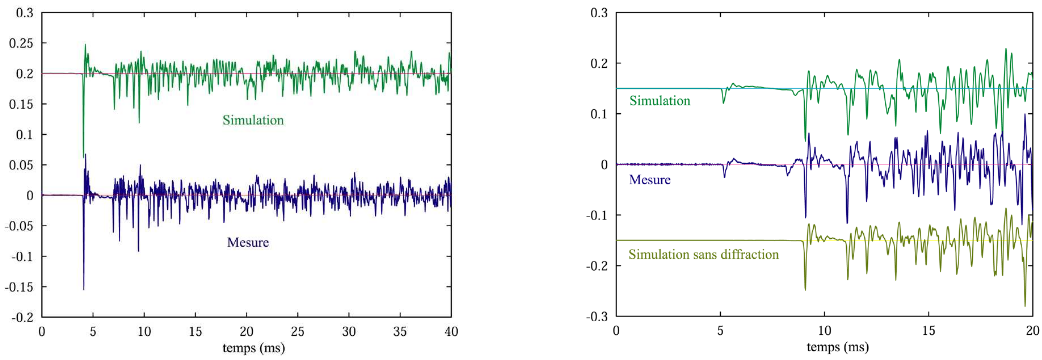


Figure 2. A comparison between a measurement (left) of the sound pressure in a given location of the "Bell Labs Box", a simple test environment built at Bell Laboratories, and a high-quality simulation based on a beam-tracing engine (right). Simulations include effects of reflections off the walls and diffraction off a panel introduced in the room.

Finally, several signal processing issues remain in order to properly and efficiently restitute a 3D soundfield to the ears of the listener over a variety of systems (headphones, speakers). We would like to develop an open and general-purpose API for audio rendering applications. We already completed a preliminary version of a software library: AURELI [39].

3.2. Virtual and Augmented Environments with Sound

The second major research direction of our group is on virtual, augmented or mixed environments, which include both visual and sound representations. We are mainly interested in interactive environments, permitting the user to create and manipulate scenes consisting of both real and synthetic objects. As a first step, we consider *real* objects to be digitised representations of reality, rather than the real world. Our first goal is to apply and adapt our rendering expertise, presented in the previous paragraphs to virtual and augmented reality. There are three areas in which we concentrate our efforts: consistent lighting between real and synthetic illumination, for shadows and reflections, enriching virtual and augmented environments with sound, in a consistent manner and finally appropriate interaction and visual paradigms for virtual and augmented environments.

3.2.1. Efficient and Simple Relighting

We wish to develop relighting and consistent real/virtual lighting methods which have simple input requirements: i.e., a small number of input images, and the smallest number of restrictions on the lighting conditions. The goal is to get high quality results for both interior and outdoors environments. To achieve these goals, we investigate ways to extract approximate reflectances in real scenes, potentially using scene or image statistics, and by including some level of user interaction in the process. For efficient display, texture capacities of modern graphics hardware will definitely be advantageous.

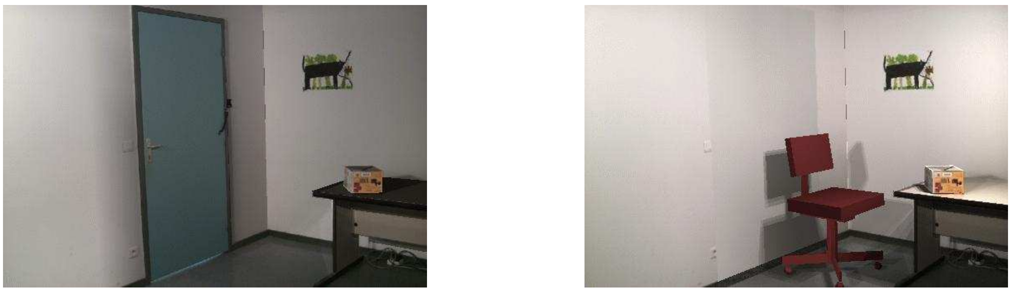


Figure 3. (a) Original conditions (b) The door has been removed virtually, and a virtual object and light have been added (method of [36])

Our previous work on interior relighting (Figure 3) has given satisfactory solutions, allowing us to add virtual object with consistent lighting, but implies severe restrictions on the lighting conditions of input images [35], [36]. Such approaches are based on the creation of "shadow free" base textures using heuristics, and a relatively precise reconstruction of the geometry. For outdoors scenes, geometric complexity and the fact that lighting conditions cannot be easily manipulated render such approaches less appropriate. However, some of the techniques developed can be applied, and we believe that the key is to combine automated techniques with user interaction at the various stages of the process. The long-term goal is to turn on a video camera in a scene (potentially with partially pre-reconstructed geometry), and be able to add virtual objects or light sources interactively in a consistent manner into the video stream. Relighting could also be achieved in this manner, or using semi-transparent glasses or headsets. Applications of such an approach are numerous, for archeology, architecture and urban planning, special effects, manufacturing, design, training, computer games etc. This long term vision will require a way to smoothly vary from low-quality methods [35], [36] to high quality approaches [42], in a manner which is much less complex in terms of capture, processing for relighting and (re)rendering.

3.2.2. Enriching virtual environments with sound

Consistent rendering of real and synthetic sounds is a key aspect for virtual reality applications. Solving the problem would make it possible to mix natural sounds with synthesized spatial audio for augmented reality applications. This can be used to enrich the natural soundscape with additional auditory information through wearable devices (e.g., virtual museums, etc.). Another application would be to provide auditory feedback to visually-impaired people while preserving their natural auditory perception. Another future direction of research is active control of rooms and listening spaces. Such control can be achieved by coupling microphones and speaker arrays and allow for modifying the natural acoustical properties of the space (e.g., reverberation time) in real-time. Such technologies have already been used to improve acoustics in concert halls that, for a variety of reasons, do not sound as good as designed for. They appear to be promising for VR/AR applications. However, existing techniques yet have to be improved to be applied in this context.

3.2.3. Interaction and Visual Paradigms for Virtual and Augmented Environments

The use of immersive or semi-immersive systems opens a large number of new types of interaction with virtual or augmented environments. There is a vast body of research on interfaces for 3D environments, and in particular for immersive systems. Our focus will be on specific interfaces, interaction or visual paradigm problems which inevitably appear in the course of our research. When necessary, we will work with complementary partners in Computer-Human Interaction to find solutions to these problems. One question we consider important is finding appropriate interface paradigms which replace 2D (menu or button-based) interfaces both in the context of the actual rendering research process and for the applications we investigate. Despite significant previous work in the domain, a standard that can be widely adopted has yet to be defined. It may be that the lack of standard interfaces is part of the reason why immersive systems are not being adopted as widely nor as rapidly as their inventors would have hoped. In terms of visual representation, non-photorealistic (NPR) or expressive, renderings are an interesting avenue of investigation. In particular, NPR can allow abstraction of unimportant details and more efficient communication of certain concepts. Since a number of the algorithms developed are based on inherently 2D drawing, their transposition to immersive, stereo-display environments poses a number of very interesting and challenging questions. There are also some applications domains, for example archeology or architecture, where drawing-style renderings are part of the current workflow, and which will naturally fit into a EVs adapted to these domains. Virtual storytelling is another domain in which NPR has a natural application. Immersive, stereo-based systems seem a well-adapted platform for more intuitive interactive modelling in 3D. The development of efficient and flexible structures such as procedural point-based representations, or rapid aging techniques in a true 3D context could result in systems which are much more efficient that 2D displays, in which the sensation of 3D depth and immersion is missing. Finally, the inclusion of spatialised sound for 3D interfaces is clearly a promising research direction. The benefit of consistent 3D sound is evident, since it results in better spatial perception for the user, can help for example in determining spatial or visibility relationships, resulting in improved usability. The actual inclusion of sound effects or sound metaphors in interface design is clearly an interesting challenge.

4. Software

4.1. APF: state-of-the-art 3D audio library

Participants: Adrien David, David Grelaud, George Drettakis.

This work was performed in collaboration with Jean-Christophe Lombardo of the DREAM research engineer service at INRIA Sophia-Antipolis Méditerranée. REVES has several audio research publications: the first component is the masking or culling algorithm, which aims at removing all the inaudible audio sources from a virtual scene based on perceptual metrics. The second component, called clustering, aims at grouping audio sources that are spatially close to each other and premix them to a representative cluster source, so that all spatialization related processing can be applied only on the representative premixed source [9]. Other audio topics were also considered and developed, like progressive and scalable frequency domain mixing, sound propagation, scalable reverberation, modal sound synthesis and contact sounds generation [1].

In order to maintain all the knowledge in the group and re-use these technologies in the Immersive Space, David Grelaud has written a fully documented audio library (APF) which gathers about 10 audio publications and 1 US patent. APF is a cross-platform, object oriented C++ API available on GForge. All the code has been re-implemented and a completely new software architecture resulted in a twofold increase in the speed of our algorithms. APF runs in the Immersive Space and uses the tracking system to spatialize virtual audio sources around the listener. It can also exploit personal Head Related Transfer Functions (HRTF). We are currently implementing a network communications layer to create an audio rendering server on a separate machine.

APF has also been critical in establishing collaborations in the context of various grant proposals (EU and national).

This year we adapted APF to the requirements of the Immersive Space.

4.2. GaborNoise Software

Participants: Ares Lagae, George Drettakis.

We proposed a new procedural noise function last year, Gabor noise [6]. In the context of this project, we have developed an software package, which includes a CPU reference implementation of the 2D noise, and a complete GPU implementation of the 2D noise, surface noise, and 3D noise. This software package has been filed for APP protection and is in the process of being transferred to industrial partners.

This work is a collaboration with Sylvain Lefebvre, former member of the team, now at INRIA Nancy.

4.3. OgreVR - A Virtual Reality Framework

Participants: David Grelaud, Adrien David, George Drettakis.

We have upgraded OgreVR which is a framework to use Ogre3D, an open-source graphics rendering engine, on virtual reality platform. OgreVR is now compatible with the I-Space and the CADWall. We have also implemented a special version of LibSL, a C++ graphics-programming toolbox originally developed by Sylvain Lefebvre, which allows us to deploy rapidly a 3d application in the Immersive Space. These two libraries are available on GForge.

5. New Results

5.1. Plausible Image Rendering

5.1.1. Proxy-Guided Texture Synthesis for Rendering Natural Scenes

Participant: George Drettakis.

Landscapes and other natural scenes are easy to photograph but difficult to model and render. We developed a method which allows for a simple 3D proxy geometry to be rendered with the rich visual detail found in a suitably pre-annotated example image such as a photograph by directly using elements from the images as 2D rendering primitives. This greatly simplifies the geometric modeling and texture mapping of such scenes. This method renders at near-interactive rates and is designed by carefully adapting guidance-based texture synthesis to our goals (Figure 4).

Figure 4. From a segmented photograph (left) and a sketched proxy, our method produces a plausible rendering where CG elements can be integrated (right).

This work is a collaboration with Nicolas Bonneel, Michiel van de Panne and Sylvain Lefebvre (former members of the team in 2009); it has been published at the 15th International Workshop on Vision, Modeling and Visualization 2010 conference [20], and was elected for the best paper award.

5.1.2. Assisted Texture Assignment

Participant: Sylvain Lefebvre.

In this work we developed an algorithm to help modelers texture large virtual environments. Modelers typically manually select a texture from a database of materials for each and every surface of a virtual environment. Our algorithm automatically propagates user input throughout the entire environment as the user is applying textures to it. After choosing textures for only a small subset of the surface, the entire scene is textured. This work, which was the research topic of Matthäus G. Chajdas during his master internship in 2009, was supervised by Sylvain Lefebvre and has been published at the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games (I3D) conference in 2010 [21].

5.1.3. By-example Synthesis of Architectural Textures

Participant: Sylvain Lefebvre.

We have developed a new texture synthesis algorithm targeted at architectural textures. While most existing algorithms support only stochastic textures, ours is able to synthesize new images from highly-structured examples such as images of architectural elements (facades, windows, doors, etc.). In addition, our approach is designed so that results are compactly encoded and quickly accessed from the graphics processor during the rendering process. Thus, when used as textures our synthesis results use little memory compared to the equivalent images they represent (Figure 5).

This work was published at SIGGRAPH 2010 (also in ACM Transactions on Graphics) [17]. This work was developed at REVES by Sylvain Lefebvre (now at ALICE), Samuel Hornus (GEOMETRICA/ALICE) and Anass Lasram (ALICE).

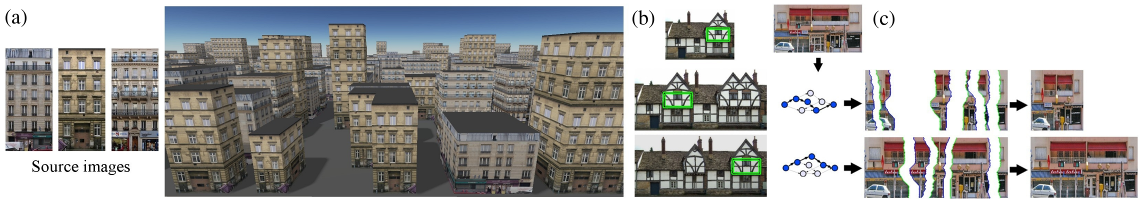


Figure 5. (a) From a source image our synthesizer generates new textures fitting surfaces of any size. (b) The user has precise control over the results. (c) Our algorithm synthesizes textures by reordering strips of the source image. Each result is a path in a graph describing the space of synthesizable images. Only the path needs to be stored in memory. Decoding is performed during display, in the pixel shader.

5.1.4. NPR Gabor Noise: A Dynamic Noise Primitive for Coherent Stylization

Participants: Ares Lagae, Peter Vangorp, George Drettakis.

We have introduced a new solution for temporal coherence in non-photorealistic rendering (NPR) of animations. Given the conflicting goals of preserving the 2D aspect (or "flatness") of the shading pattern and the 3D scene motion, while at the same time avoiding temporal discontinuities (or "popping"), any such solution is a trade-off. We observe that primitive-based methods in NPR can be seen as texture-based methods when using large numbers of primitives, leading to our key insight, namely that this process is similar to sparse convolution noise in procedural texturing. Consequently, we present a new primitive for NPR based on Gabor noise [6], that preserves the 2D aspect of noise, conveys the 3D motion of the scene, and is temporally continuous. We can thus use standard techniques from procedural texturing to create various styles (Figure 6), which we show for interactive NPR applications. We also conducted the first user study to evaluate this and existing solutions thoroughly and objectively, and to provide more insight in the trade-off implied by temporal coherence. The results of the study indicate that maintaining coherent motion is important, but also that our new solution provides a good compromise between the 2D aspect of the style and 3D motion.

This work is a collaboration with Pierre G. Bénard and Joëlle Thollot (Grenoble University, ARTIS / INRIA Grenoble), and Sylvain Lefebvre (ALICE/INRIA Nancy Grand-Est). The work was published in the special issue of the journal Computer Graphics Forum [13], presented at the Eurographics Symposium on Rendering 2010, and also presented at the ACM SIGGRAPH 2010 Technical Talks program [25].

5.1.5. Improving Gabor Noise

Participant: Ares Lagae.

We have recently proposed a new procedural noise function, Gabor noise. In a follow up project, we present three significant improvements to Gabor noise: (1) an isotropic kernel for Gabor noise, which speeds up isotropic Gabor noise with a factor of roughly two, (2) an error analysis of Gabor noise, which relates the kernel truncation radius to the relative error of the noise, and (3) spatially varying Gabor noise, which enables spatial variation of all noise parameters. These improvements make Gabor noise an even more attractive alternative for existing noise functions.

This work is a collaboration with Sylvain Lefebvre (ALICE/INRIA Nancy Grand-Est) and Philip Dutré (KU Leuven) and has been accepted for publication [16].

5.1.6. Filtered Solid Noise

Participants: Ares Lagae, George Drettakis.

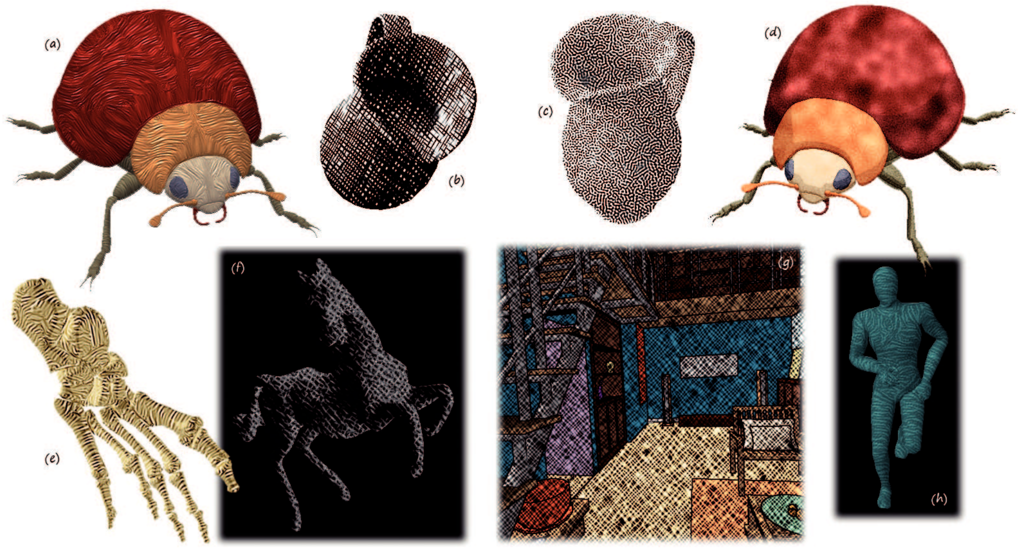


Figure 6. A variety of styles produced with NPR Gabor Noise: (a) painterly rendering with bump mapped brush fibers, (b,c,f) cross hatching and stippling with density linked to shading, (d) watercolor pigments on paper texture, (e,h) hatching oriented to follow geometric curvature, (g) felt-tip pen patterns.

Existing noise functions either do not support high-quality filtering, which is the case for Perlin noise and wavelet noise, or introduces discontinuities of the solid noise at sharp corners, which is the case for wavelet noise and Gabor noise. We present a new noise function that supports both high-quality filtering as well as solid noise in the presence of sharp corners.

5.1.7. State of the Art in Procedural Noise Functions

Participants: George Drettakis, Ares Lagae.

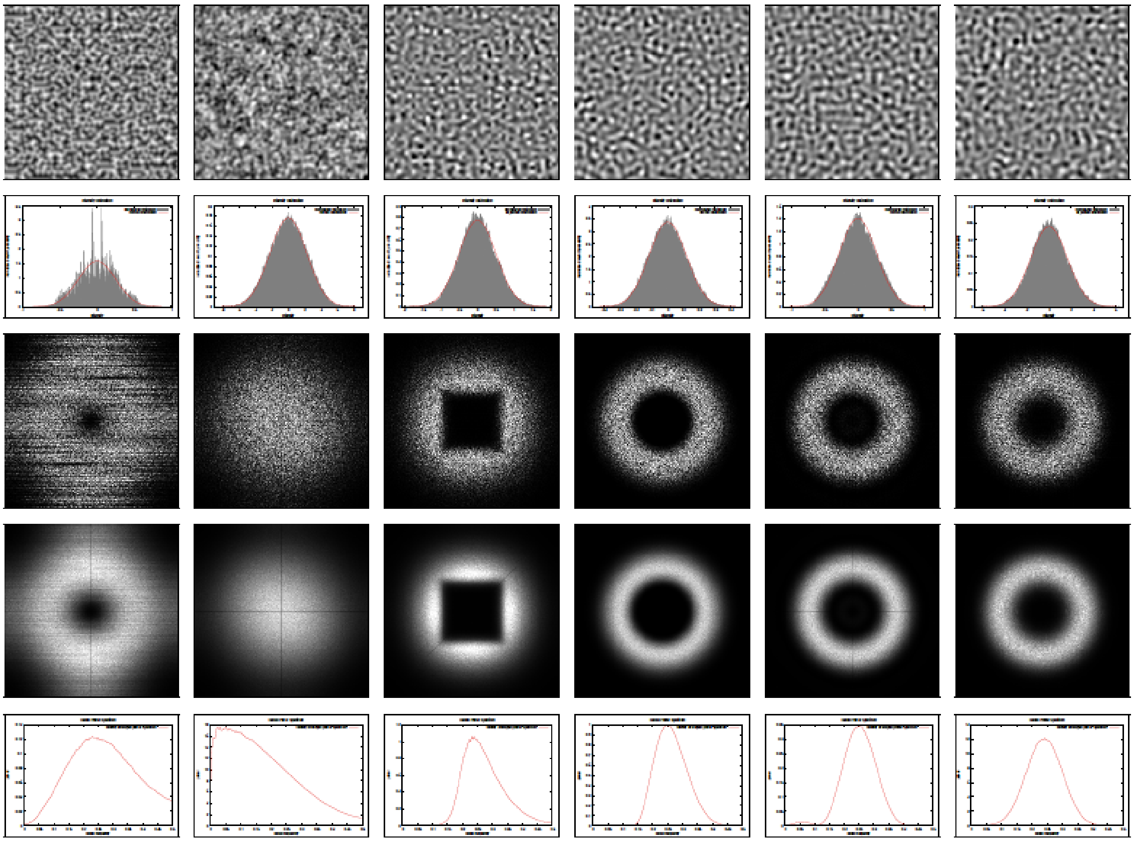
This survey is motivated by the inherent importance of noise in graphics, the widespread use of noise in industry, and the fact that many recent research developments justify the need for an up-to-date survey. Our goal is to provide both a valuable entry point into the field of procedural noise functions, as well as a comprehensive view of the field to the informed reader. In this report, we cover procedural noise functions in all their aspects. We outline recent advances in research on this topic, discussing and comparing recent and well established methods. This is illustrated in Figure 7.

This work is a collaboration with Sylvain Lefebvre (now at ALICE/INRIA Nancy Grand-Est), Rob Cook and Tony DeRose (Pixar Animation Studios), D.S. Ebert (Purdue University), J.P. Lewis (Weta Digital), Ken Perlin (NY University) and Matthias Zwicker (University of Berne) and was presented at EUROGRAPHICS 2010 [24] and published in Computer Graphics Forum [15].

5.1.8. Relighting photographs of Tree Canopies

Participants: Marcio Cabral, George Drettakis.

We developed a solution for relighting of tree canopy photographs. The input is simply a set of photographs at a single time of day. We use information from the images to develop a single scattering volumetric rendering model approximation. By using this model and combining it with an analytical sun/sky model, we are able to relight the tree photographs at any other target time of day. Our goal is to minimize capture overhead; thus the only input required is a set of photographs of the tree taken at a *single* time of day, while allowing relighting at any other time.



(a) Perlin noise. (b) Sp. convo. noise. (c) Wavelet noise. (d) Anisotrop. noise. (e) Bet. gra. noise. (f) Gabor noise.

Figure 7. State of the Art in Procedural Noise Functions. An important part of this work is an analysis of procedural noise function. This figure shows (top row to bottom row) the noise, the amplitude distribution, the periodogram, the power spectrum estimate, and the radially averaged power spectrum estimate for (left column to right column) Perlin noise, sparse convolution noise, wavelet noise, anisotropic noise, better gradient noise and Gabor noise.

We first analyze lighting in a tree canopy both theoretically and using simulations. From this analysis, we observe that tree canopy lighting is similar to volumetric illumination. We assume a single-scattering volumetric lighting model for tree canopies, and diffuse leaf reflectance; we validate our assumptions with synthetic renderings.

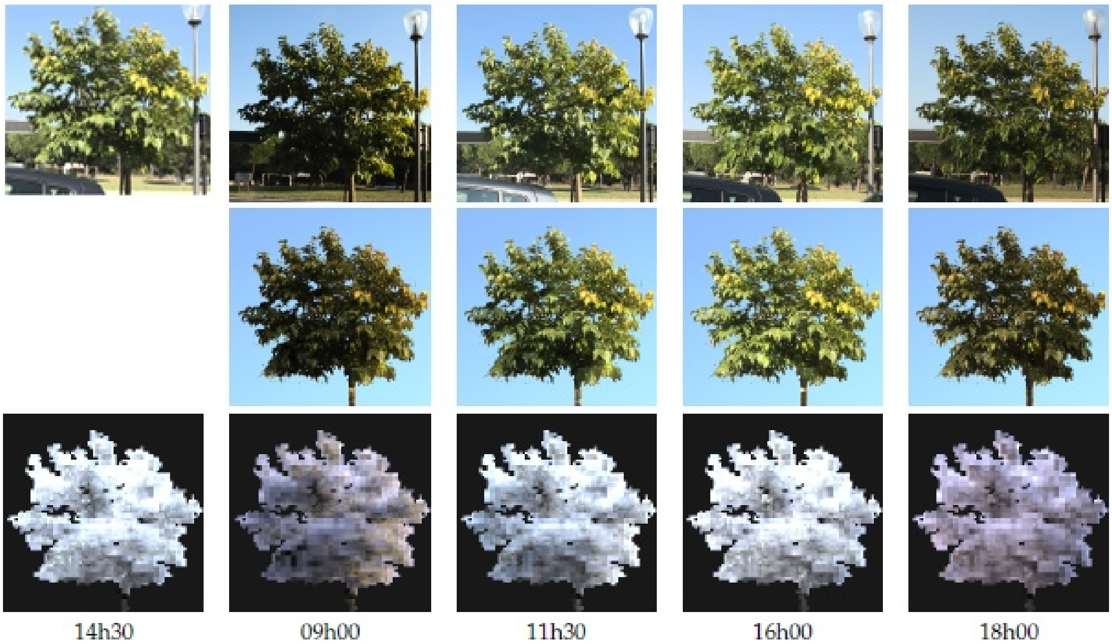


Figure 8. First row: input photograph followed by 4 ground truth photographs taken at different times of the day. Second row: relighting results from our method. Third row: Approximate reconstructed volumetric representation of the tree canopy.

We create a volumetric representation (see last row of Figure 8) of the tree from 10-12 images taken at a single time of day and use a single-scattering participating media lighting model. An analytical sun and sky illumination model provides consistent representation of lighting for the captured input and unknown target times. We relight the input image by applying a ratio of the target and input time lighting representations. We compute this representation efficiently by simultaneously coding transmittance from the sky and to the eye in spherical harmonics. We validate our method by relighting images of synthetic trees and comparing to path-traced solutions. We also present results for photographs, validating with time-lapse ground truth sequences (see first and second rows of Figure 8). This work will appear in IEEE Transactions on Computer Graphics and Visualization [14].

5.1.9. Image-Guided Weathering: A New Approach Applied to Flow Phenomena

Participants: Carles Bosch, Pierre-Yves Laffont, George Drettakis.

The simulation of weathered appearance is essential in the realistic modeling of urban environments. A representative and particularly difficult effect to produce on a large scale is the effect of fluid flow. With digital photography and Internet image collections, visual examples of flow effects are readily available. These images, however, mix the appearance of flows with the specific local context. We have proposed a methodology to extract parameters and detail maps from existing imagery in a form that new target specific flow effects can be produced, with natural variations in the effects as they are applied in different locations in a new scene. Our contribution is a new approach to weathering that uses photographs to drive a simulation, rather than simply reusing the photograph or patches of pixels from the photograph directly. Using this approach, a rich collection of patterns have been successfully applied to urban models.

This work is a collaboration with Holly Rushmeier and Julie Dorsey from Yale University, and is in revision for ACM Transaction on Graphics.

5.1.10. Perception of Image Based Rendering

Participants: Peter Vangorp, George Drettakis, Gaurav Chaurasia.

Image based rendering (IBR) techniques for relatively sparse image collections typically project those images onto an approximate geometric reconstruction of the scene. Small misalignments and lack of geometric detail can cause a range of visible artifacts including ghosting, perspective deformations, and temporal discontinuities (or "popping"). The goal of this research is to study the influence of image collection density, blending strategy, viewing angle, and depth distribution on the visual quality in the typical application setting of façades. Additionally, objective measures will be developed for predicting visual quality and guiding image acquisition.

This work is an ongoing collaboration with Roland W. Fleming (Justus-Liebig-Universität Gießen).

5.2. Plausible Audio Rendering

5.2.1. Advances in Modal Analysis Using a Robust and Multi-Scale Method

Participant: George Drettakis.

This work was developed in the Ph.D. of Cécile Picard who finished last year. We present a new approach to modal synthesis for rendering sounds of virtual objects. We propose a generic method that preserves sound variety across the surface of an object, at different scales of resolution and for a variety of complex geometries. The technique performs automatic voxelization of a surface model and automatic tuning of the parameters of hexahedral finite elements, based on the distribution of material in each cell. The voxelization is performed using a sparse regular grid embedding of the object, which permits the construction of plausible lower resolution approximations of the modal model. Our model approximates the motion of the embedded mesh vertices. That is, the visual model with detailed geometry does not match the mechanical model on which the modal analysis is performed. The motion of the embedding uses a trilinear interpolation of the mechanical degrees of freedom, so we can nevertheless compute the motion of any point on the surface given the mode shapes. The modal parameters are extracted in a preprocessing step by solving the equation of motion for small linear deformations.

We have also developed an interface for sound design based on this work (Figure 9).

This work was published in the EURASIP journal on Advances in Signal Processing[18], and is a collaboration with C. Frisson, Francois Faure (EVASION, Grenoble) and Paul Kry (McGill U.).

5.3. Interaction and Rendering for Audiovisual Virtual Environments

5.3.1. Bimodal perception of audio-visual material properties for virtual environments

Participant: George Drettakis.

In this project we studied the audio-visual interaction for the estimation of material quality when varying audio LOD (number of modes for contact sounds) and visual LOD (number of spherical harmonic coefficients for BRDF rendering). We performed a perceptual experiment with two models (a bunny and a dragon) falling on a table and producing an impact sound. The models were made of plastic or gold: modes were computed with these materials for the impact sounds, and measured BRDFs data were used for the visual rendering. The participant had to rate the similarity in terms of material between a high quality rendering (for both audio and visuals) and an approximation. This similarity with a reference rendering is interpreted as a measure of quality. The experiment (Figure 10) showed such a crossmodal interaction: the effects of the visual LOD and audio LOD on the perceived material quality are not independent. We further showed that for all audio qualities, 7 or 9 spherical harmonic bands was not perceived differently as the high quality approximation for material quality estimation.

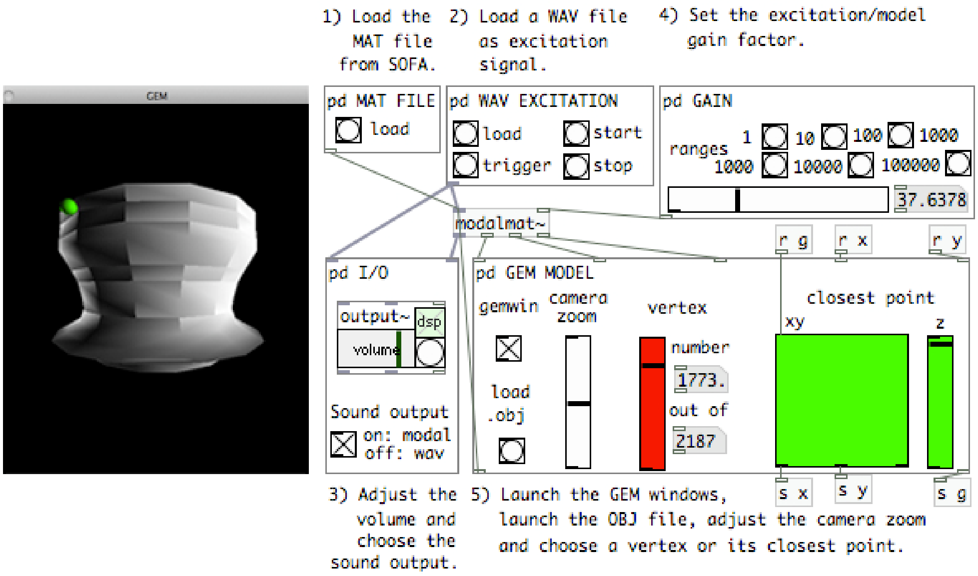


Figure 9. Interface for sound design. After having loaded the modal data and the corresponding mesh geometry, the user can experiment the modal sounds when exciting the object surface at different locations. Excitation signals may be loaded as recorded sound samples or real-time tracked from live soundcard inputs.

This work was part of the Ph.D. of Nicolas Bonneel (former Ph.D. student in the team in 2009) in collaboration with Clara Suied and Isabelle Viaud-Delmon (CNRS/IRCAM), and has been published in ACM Transactions on Applied Perception [11].

5.3.2. *Interactive Content-Aware Zooming*

Participants: Pierre-Yves Laffont, George Drettakis.

We introduced a novel, interactive content-aware zooming operator that allows effective and efficient visualization of high resolution images on small screens, which may have different aspect ratios compared to the input images.

Our approach first applies a content-aware retargeting method based on [41], augmented with additional constraints to prevent the deformation of straight lines. This can provide global, but approximate views for lower zoom levels. Then, as we zoom more closely into the image, we continuously *unroll* the distortion to provide local, but more detailed and accurate views for higher zoom levels. Figure 11 shows an example of this process, and compares our results with those of the traditional zooming approach, and a method stemming from a direct combination of existing works.

This work is a collaboration with Christian Wolf, Khalid Idrissi (LIRIS, Lyon), and Jong Yun Jun, Yu-Wing Tai, Sung-eui Yoon (KAIST, Korea) and was presented at Graphics Interface 2010 [22].

5.3.3. *A Multimode Immersive Conceptual Design System for Architectural Modeling and Lighting*

Participants: Marcio Cabral, George Drettakis, Gaurav Chaurasia, Emmanuelle Chapoulie, Peter Vangorp.

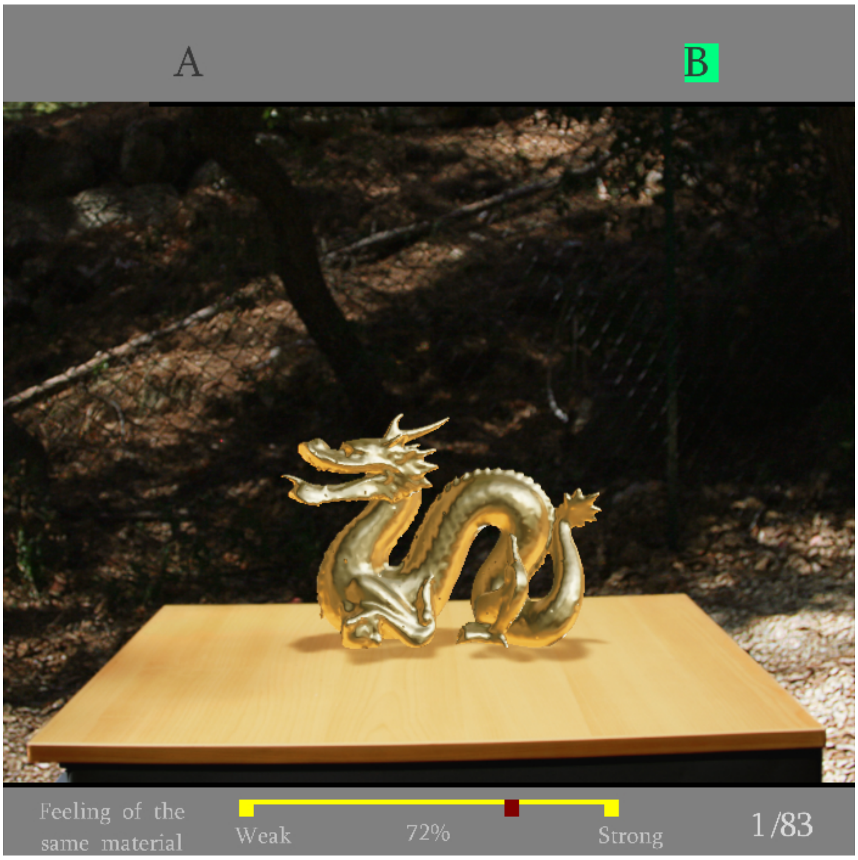


Figure 10. Screenshot of the experiment. The participant has to rate the similarity in terms of material on a scale between 0 and 100, taking into account both the visual rendering of the dragon and its impact sound.

*Figure 11. Top: traditional zooming; middle: Retargeting+Zooming; bottom: our Interactive Content-Aware Zooming method. We use a 7475×1999 pixels input image and varying zoom levels. Traditional zooming wastes a lot of screen space at lower zoom levels, with black bands covering most of the screen and a significant loss of resolution (first row, column **a**). The second approach, which combines zooming with content-aware retargeting [41], better utilizes the screen space (second row, column **a**) but suffers from heavy distortion at higher zoom levels (second row, column **d**). In comparison, our method shows global, but approximate views for lower zoom levels, and local, but accurate views for higher zoom levels (third row).*

We presented a new immersive system which allows initial conceptual design of simple architectural models, including lighting. Our system allows the manipulation of simple elements such as windows, doors and rooms while the overall model is automatically adjusted to the manipulation. The system runs on a four-sided stereoscopic, head-tracked immersive display. We also provide simple lighting design capabilities, with an abstract representation of sunlight and its effects when shining through a window. Our system provides three different modes of interaction: a miniature-model table mode, a full scale immersive mode and a combination of table and immersive which we call mixed mode. We performed an initial pilot user test to evaluate the relative merits of each mode for a set of basic tasks such as resizing and moving windows or walls, and a basic light-matching task. The study indicates that users appreciated the immersive nature of the system, and found interaction to be natural and pleasant. In addition, the results indicate that the mean performance times seem quite similar in the different modes, opening up the possibility for their combined usage for effective immersive modeling systems for novice users. This work has been submitted for publication.

6. Contracts and Grants with Industry

6.1. Grants with Industry

6.1.1. Adobe

In the context of our collaboration with Adobe, we have received a cash donation in support of our research.

6.1.2. NVIDIA

We have received several graphics cards as part of the professor partnership program.

6.1.3. Autodesk

Autodesk has donated several licenses of Maya and 3DS Max.

6.2. National Initiatives

6.2.1. ARC NIEVE: Navigation and Interfaces in Emotional Virtual Environments

Participants: Peter Vangorp, Adrien David, George Drettakis, Gaurav Chaurasia, Emmanuelle Chapoulie.

The goal of this joint research project is to develop and evaluate improved interfaces for navigation in immersive virtual environments (VEs) such as the 4-wall stereoscopic iSpace system in the Immersive Space Gouraud-Phong.

There is evidence of significant overlap in brain structures related to spatial memory and orientation and those related to emotion. We will examine the influence of high-quality 3D visual and auditory stimuli on the emotions evoked by the virtual environment. Our study will focus on the phobia of dogs as a way to modulate emotion in audiovisual VEs (Figure 12).

Navigation in VEs involves the use of different views, i.e., egocentric (“first person”) and allocentric (“bird’s eye”) views during navigation tasks. We will study appropriate visual representations for each view (for example, the level of realism ranging from abstract map-like rendering for top-down views to photorealistic rendering for first-person views), and appropriate transitions between the different views.

We will develop an appropriate methodology to evaluate such navigation interfaces in stressful environments, based on the insights gained by the emotion modulation study in phobic settings. This novel methodology can be seen as a “stress-test” for navigation interfaces: if the navigation interfaces developed are successful even in stressful setups, they will definitely be successful under “normal conditions”.

This is a joint research project with Isabelle Viaud-Delmon (IRCAM, CNRS), Anatole Lécuyer and Maud Marchal (BUNRAKU / INRIA Rennes), and Jean-Christophe Lombardo (DREAM / INRIA Sophia Antipolis). Interact3D (Section 6.2.2) is associated with this ARC.

Figure 12. A person immersed in a virtual environment where the behaviors of several dogs will evoke different levels of anxiety.

6.2.2. ADT Interact3D

Participants: Adrien David, George Drettakis.

This ADT involves half time software development for ARC NIEVE, and the other half general support to the new Immersive Space Gouraud-Phong in Sophia-Antipolis (supervised by Jean-Christophe Lombardo of the DREAM service). Among its contributions are the improvement of the 3D audio spatialization capacities of APF (a previous ADT contribution), adding functionalities to our current Ogre3D based platform to allow first experiments, and the development of a generic Virtual Reality framework addressing neuroscience/psychology applications. This generic platform aims at a high-quality context abstraction to be usable in several domains, as well as distributed rendering capacities. These improvements, deployable for a variety of applications to come, are tightly coupled with the current ARC NIEVE, thus contributing to its implementation. Future prospects for the ADT Interact 3D include developing novel multimodal interaction techniques for immersive virtual environments (with positive impacts on interaction, immersion and security) and providing formal support for experimental setups (measuring latencies and reliability).

6.2.3. National French Bilateral Collaboration

We continue collaboration with the Sylvain Lefebvre who moved from REVES to ALICE last year; we also worked with S. Hornus (previously at GEOMETRICA and now a permanent researcher at ALICE). We have ongoing collaborations with J. Thollot (INPG/INRIA Grenoble), M. Hachet (IPARLA, Bordeaux), A. Lécuyer (BUNRAKU, Rennes), I. Viaud-Delmon (IRCAM) and B. Galerne (ENST/ENS Cachan). We also collaborated with Christian Wolf and Khalid Idrissi of the LIRIS laboratory in Lyon.

7. Other Grants and Activities

7.1. Bilateral Collaborations

7.1.1. France-USA

We have an ongoing collaboration (C. Bosch) with Yale University (Holly Rushmeier and Julie Dorsey), on the topic of effective and efficient weathering techniques resulting in a submitted paper.

We have an ongoing collaboration with Adobe Research (Sylvain Paris), on stereo stylized rendering.

We have started a collaboration with New York University (Olga Sorkine) on image-based rendering techniques in the context of the Ph.D. of G. Chaurasia.

A. Bousseau is continuing his collaboration with the University of California Berkeley (M. Agrawala, R. Ramamoorthi); P-Y Laffont visited Berkeley this summer in the context of this collaboration.

7.1.2. France-Germany

We have started a collaboration with R. Fleming (previously Max Planck and now Univ. Giessen) on perception for Image-Based rendering.

As a followup of the Master's thesis of Matthäus G. Chajdas, we continued our long-standing collaboration with the University of Erlangen (Marc Stamminger), resulting in [21].

7.1.3. France-Korea

Pierre-Yves Laffont finalized his Masters work in collaboration with the Scalable Graphics Lab in KAIST, South Korea (Sung-Eui Yoon), on the topic of interactive content-aware image resizing and zooming which resulted in the publication of [22].

7.1.4. France-Belgium

We have continued the collaboration with A. Lagae and P. Dutré and the Catholic University of Leuven, resulting in the publications [23], [16], [25], [13], [24], [15].

7.2. Visiting Researchers

Ares Lagae, from KU Leuven (FWO Belgium), visited the REVES research group for a year since October 2009, as a post-doctoral researcher.

Peter Vangorp, from KU Leuven, Belgium, is visiting the REVES research group for two years since October 2009, as a post-doctoral researcher.

Carles Bosch, from Univ. of Girona, Spain is visiting the REVES research group for a year since April 2010, as a post-doctoral researcher.

Gaurav Chaurasia, from IIT Delhi, India, completed his M2 (5th year) internship (Feb-Aug. 2010) and has started his Ph.D in the REVES research group in September.

We hosted several visiting researchers this year: Roland W. Fleming (Max Planck Institute for Biological Cybernetics) in April, Bruno Galerne in April, Brian Barsky (Univ. of California, Berkeley) in May, Holly Rushmeier (Yale University in May, Eugene Fiume (U. Toronto) in June, Doug DeCarlo (Rutgers University) in June, Fabio Pellacini (Dartmouth University) in July, Sylvain Paris (Adobe) in September and Charles Verron (LMA, Marseille) November.

8. Dissemination

8.1. Participation in the Community

8.1.1. Program Committees

George Drettakis is chair of the program committee of SIGGRAPH Asia 2010, which will take place in Seoul (Korea) in December. Carles Bosch has served on Eurographics Spanish Chapter Conference (CEIG) program committee.

8.1.2. Invited Talks

G. Drettakis gave keynote talks at the Eurographics Symposium on Rendering in Saarbrücken (June) and the 3DPVT conference in Paris (May). Carles Bosch presented his work at the Visual Computing Lab at CNR, Pisa, Italy, during his visit to this lab. P. Vangorp presented NPR Gabor Noise (among other topics) at the Department of General and Experimental Psychology at Justus-Liebig-Universität Gießen on August 16, 2010.

8.1.3. Thesis Committees

G. Drettakis was a member of the Habilitation committee of A. Lécuyer (Rennes) and was the examiner (rapporteur) of the Habilitation thesis of M. Hachet and the Ph.D. thesis of R. Vergne (Bordeaux).

8.1.4. Community service

G. Drettakis was a member of the "Bureau de Comité de Projets" until June and is a member of the "comité d'animation scientifique" for the Interaction, Cognition and Perception theme of INRIA since October 2009.

G. Drettakis chairs the Eurographics (EG) Awards Committee and the EG Working group on Rendering and is part of the EG conference steering committee. He is an associate editor for IEEE Transactions on Computer Graphics and Visualization.

8.1.5. Conference Presentations and Attendance

Ares Lagae presented the work [24] at EUROGRAPHICS 2010, and gave a seminar at INRIA Grenoble. P-Y Laffont presented the work [22] at Graphics Interface 2010 in Ottawa, Canada. P. Vangorp and A. Lagae attended EGSR 2010. G. Drettakis and A. Lagae attended SIGGRAPH 2010 and EUROGRAPHICS 2010. G. Drettakis and P-Y Laffont attended SIGGRAPH Asia 2010 (Seoul).

8.2. Teaching

George Drettakis is the organizer of the Computer Graphics class at Ecole Centrale Paris, and taught for 6 hours at this course. Together with Jean-Christophe Lombardo they gave an introductory course (9 hours) on image synthesis for the masters program of EPU UNSA (Jeux Video).

8.2.1. PhD Thesis Completed and Continuing

Marcio Cabral was in his 3rd year working on procedural techniques for modelling and on image-based relighting as well as immersive interfaces; he is scheduled to defend in March 2011. P-Y. Laffont is continuing his Ph.D. started Oct. 2009; G. Chaurasia and E. Chapoulie started their Ph.D.'s Sept. and Oct. 2010 respectively.

8.3. Demonstrations and Press

8.3.1. Demonstrations

Participants: David Grelaud, Adrien David, George Drettakis.

We performed many demonstrations this year, mostly in the Immersive Space, including the companies Optis and CS, the local hospital (CHU), students of Centrale, Pole ICI, the deans of Stanford Medical School and as part of the inauguration of the immersive space (many local politicians).

8.3.2. Press

Participant: George Drettakis.

As part of the Immersive space inauguration we participated in the general-public films and press releases and an article in the Inedit INRIA magazine. There was significant press coverage for this event (France 2 etc.) N. Bonneel gave an interview concerning his work [20] in the web community 3dvf: http://www.3dvf.com/forum/3dvf/Actualites/naturelles-esquisse-scenes-sujet_290_1.htm.

G. Drettakis also produced the SIGGRAPH Asia Technical Papers trailer http://www.youtube.com/watch?v=4xobWgoap9I as part of his duties as SIGGRAPH Asia technical papers chair (over 9000 views to date).

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