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CNRS

Université de Bordeaux

Institut d'Optique Graduate School

Activity Report 2014

Project-Team MANAO

Melting the frontiers between Light, Shape and Matter

IN COLLABORATION WITH: Laboratoire Bordelais de Recherche en Informatique (LaBRI), Laboratoire Photonique, Numérique et Nanosciences

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THEME
Interaction and visualization

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Project-Team MANAO

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2. Overall Objectives

2.1. General Introduction

Computer generated images are ubiquitous in our everyday life. Such images are the result of a process that has seldom changed over the years: the optical phenomena due to the propagation of *light* in a 3D environment are simulated taking into account how light is scattered [65], [43] according to *shape* and *material* characteristics of objects. The **intersection of optics** (for the underlying laws of physics) and **computer science** (for its modeling and computational efficiency aspects) provides a unique opportunity to tighten the links between these domains in order to first improve the image generation process (computer graphics, optics and virtual reality) and next to develop new acquisition and display technologies (optics, mixed reality and machine vision).

Most of the time, light, shape, and matter properties are studied, acquired, and modeled separately, relying on realistic or stylized rendering processes to combine them in order to create final pixel colors. Such modularity, inherited from classical physics, has the practical advantage of permitting to reuse the same models in various contexts. However, independent developments lead to un-optimized pipelines and difficult-to-control solutions since it is often not clear which part of the expected result is caused by which property. Indeed, the most efficient solutions are most often the ones that **blur the frontiers between light, shape, and matter** to lead to specialized and optimized pipelines, as in real-time applications (like Bidirectional Texture Functions [77] and Light-Field rendering [41]). Keeping these three properties separated may lead to other problems. For instance:

- Measured materials are too detailed to be usable in rendering systems and data reduction techniques have to be developed [75], [78], leading to an inefficient transfer between real and digital worlds;
- It is currently extremely challenging (if not impossible) to directly control or manipulate the interactions between light, shape, and matter. Accurate lighting processes may create solutions that do not fulfill users' expectations;
- Artists can spend hours and days in modeling highly complex surfaces whose details will not be visible [99] due to inappropriate use of certain light sources or reflection properties.

Most traditional applications target human observers. Depending on how deep we take into account the specificity of each user, the requirement of representations, and algorithms may differ.

Auto-stereoscopy display ©Nintendo

HDR display ©Dolby Digital

Printing both geometry and material [57]

Figure 1. Examples of new display technologies. Nowadays, they are not limited to a simple array of 2D low-dynamic RGB values.

With the evolution of measurement and display technologies that go beyond conventional images (e.g., as illustrated in Figure 1, High-Dynamic Range Imaging [88], stereo displays or new display technologies [61], and physical fabrication [30], [49], [57]) the frontiers between real and virtual worlds are vanishing [45]. In this context, a sensor combined with computational capabilities may also be considered as another kind of observer. Creating separate models for light, shape, and matter for such an extended range of applications and observers is often inefficient and sometimes provides unexpected results. Pertinent solutions must be able to **take into account properties of the observer** (human or machine) and application goals.

2.2. Methodology

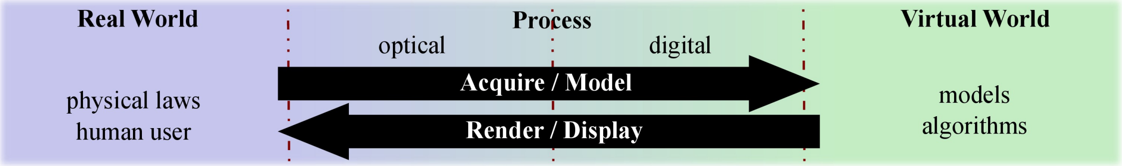


Figure 2. Interactions/Transfers between real and virtual worlds. One of our goal is to combine optical instruments with processes from computer science in order to blend the two worlds.

2.2.1. Using a global approach

The main goal of the *MANAO* project is to study phenomena resulting from the interactions between the three components that describe light propagation and scattering in a 3D environment: light, shape, and matter. Improving knowledge about these phenomena facilitates the adaption of the developed digital, numerical, and analytic models to specific contexts. This leads to the development of new analysis tools, new representations, and new instruments for acquisition, visualization, and display.

To reach this goal, we have to first increase our understanding of the different phenomena resulting from the interactions between light, shape, and matter. For this purpose, we consider how they are captured or perceived by the final observer, taking into account the relative influence of each of the three components. Examples include but are not limited to:

- The manipulation of light to reveal reflective [38] or geometric properties [9], as mastered by professional photographers;
- The modification of material characteristics or lighting conditions [10] to better understand shape features, for instance to decipher archaeological artifacts;
- The large influence of shape on the captured variation of shading [86] and thus on the perception of material properties [103].

Based on the acquired knowledge of the influence of each of the components, we aim at developing new models that combine two or three of these components. Examples include the modeling of Bidirectional Texture Functions (BTFs) [48] that encode in a unique representation effects of parallax, multiple light reflections, and also shadows without requiring to store separately the reflective properties and the meso-scale geometric details, or Light-Fields that are used to render 3D scenes by storing only the result of the interactions between light, shape, and matter both in complex real environments and in simulated ones.

One of the strengths of *MANAO* is that we are inter-connecting computer graphics and optics. On one side, the laws of physics are required to create images but may be bent to either increase performance or user's control: this is one of the key advantage of computer graphics approach. It is worth noticing that what is not possible in the real world may be possible in a digital world. However, on the other side, the introduced approximations may help to better comprehend the physical interactions of light, shape, and matter.

2.2.2. *Taking observers into account*

The *MANAO* project specifically aims at considering information transfer, first from the real world to the virtual world (acquisition and creation), then from computers to observers (visualization and display). For this purpose, we use a larger definition of what an observer is: it may be a human user or a physical sensor equipped with processing capabilities. Sensors and their characteristics must be taken into account in the same way as we take into account the human visual system in computer graphics. Similarly, computational capabilities may be compared to cognitive capabilities of human users. Some characteristics are common to all observers, such as the scale of observed phenomena. Some others are more specifics to a set of observers. For this purpose, we have identified two classes of applications.

- **Physical systems**: Provided our partnership that leads to close relationships with optics, one novelty of our approach is to extend the range of possible observers to physical sensors in order to work on domains such as *simulation, mixed reality, and testing*. Capturing, processing, and visualizing complex data is now more and more accessible to everyone, leading to the possible convergence of real and virtual worlds through visual signals. This signal is traditionally captured by cameras. It is now possible to augment them by projecting (e.g., the infrared laser of Microsoft Kinect) and capturing (e.g., GPS localization) other signals that are outside the visible range. These supplemental information replace values traditionally extracted from standard images and thus lower down requirements in computational power [72]. Since the captured images are the result of the interactions between light, shape, and matter, the approaches and the improved knowledge from *MANAO* help in designing interactive acquisition and rendering technologies that are required to merge the real and the virtual world. With the resulting unified systems (optical and digital), transfer of pertinent information is favored and inefficient conversion is likely avoided, leading to new uses in interactive computer graphics applications, like augmented reality [36], [45] and computational photography [87].
- **Interactive visualization**: This direction includes domains such as *scientific illustration and visualization, artistic or plausible rendering*. In all these cases, the observer, a human, takes part in the process, justifying once more our focus on real-time methods. When targeting average users, characteristics as well as limitations of the human visual system should be taken into account: in particular, it is known that some configurations of light, shape, and matter have masking and facilitation effects on visual perception [99]. For specialized applications, the expertise of the final user and the constraints for 3D user interfaces lead to new uses and dedicated solutions for models and algorithms.

3. Research Program

3.1. Related Scientific Domains

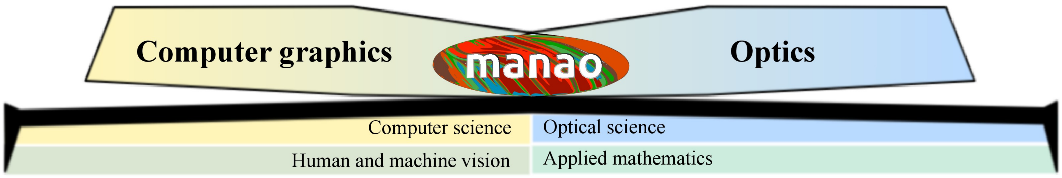


Figure 3. Related scientific domains of the MANAO project.

The *MANAO* project aims to study, acquire, model, and render the interactions between the three components that are light, shape, and matter from the viewpoint of an observer. As detailed more lengthily in the next section, such a work will be done using the following approach: first, we will tend to consider that these three components do not have strict frontiers when considering their impacts on the final observers; then, we will not only work in **computer graphics**, but also at the intersections of computer graphics and **optics**, exploring the mutual benefits that the two domains may provide. It is thus intrinsically a **transdisciplinary** project (as illustrated in Figure 3) and we expect results in both domains.

Thus, the proposed team-project aims at establishing a close collaboration between computer graphics (e.g., 3D modeling, geometry processing, shading techniques, vector graphics, and GPU programming) and optics (e.g., design of optical instruments, and theories of light propagation). The following examples illustrate the strengths of such a partnership. First, in addition to simpler radiative transfer equations [50] commonly used in computer graphics, research in the later will be based on state-of-the-art understanding of light propagation and scattering in real environments. Furthermore, research will rely on appropriate instrumentation expertise for the measurement [62], [63] and display [61] of the different phenomena. Reciprocally, optics researches may benefit from the expertise of computer graphics scientists on efficient processing to investigate interactive simulation, visualization, and design. Furthermore, new systems may be developed by unifying optical and digital processing capabilities. Currently, the scientific background of most of the team members is related to computer graphics and computer vision. A large part of their work have been focused on simulating and analyzing optical phenomena as well as in acquiring and visualizing them. Combined with the close collaboration with the optics laboratory (LP2N) and with the students issued from the "Institut d'Optique", this background ensures that we can expect the following results from the project: the construction of a common vocabulary for tightening the collaboration between the two scientific domains and creating new research topics. By creating this context, we expect to attract (and even train) more trans-disciplinary researchers.

At the boundaries of the *MANAO* project lie issues in **human and machine vision**. We have to deal with the former whenever a human observer is taken into account. On one side, computational models of human vision are likely to guide the design of our algorithms. On the other side, the study of interactions between light, shape, and matter may shed some light on the understanding of visual perception. The same kind of connections are expected with machine vision. On the one hand, traditional computational methods for acquisition (such as photogrammetry) are going to be part of our toolbox. On the other hand, new display technologies (such as augmented reality) are likely to benefit from our integrated approach and systems. In the *MANAO* project we are mostly users of results from human vision. When required, some experimentation might be done in collaboration with experts from this domain, like with the European PRISM project (cf. Section TODO). For machine vision, provided the tight collaboration between optical and digital systems, research will be carried out inside the *MANAO* project.

Analysis and modeling rely on **tools from applied mathematics** such as differential and projective geometry, multi-scale models, frequency analysis [52] or differential analysis [86], linear and non-linear approximation techniques, stochastic and deterministic integrations, and linear algebra. We not only rely on classical tools, but also investigate and adapt recent techniques (e.g., improvements in approximation techniques), focusing on their ability to run on modern hardware: the development of our own tools (such as Eigen, see Section 4.1.2) is essential to control their performances and their abilities to be integrated into real-time solutions or into new instruments.

3.2. Research axes

The *MANAO* project is organized around four research axes that cover the large range of expertise of its members and associated members. We briefly introduce these four axes in this section. More details and their inter-influences that are illustrated in the Figure 2 will be given in the following sections.

Axis 1 is the theoretical foundation of the project. Its main goal is to increase the understanding of light, shape, and matter interactions by combining expertise from different domains: optics and human/machine vision for the analysis and computer graphics for the simulation aspect. The goal of our analyses is to identify the different layers/phenomena that compose the observed signal. In a second step, the development of physical simulations and numerical models of these identified phenomena is a way to validate the pertinence of the proposed decompositions.

In Axis 2, the final observers are mainly physical captors. Our goal is thus the development of new acquisition and display technologies that combine optical and digital processes in order to reach fast transfers between real and digital worlds, in order to increase the convergence of these two worlds.

Axes 3 and 4 focus on two aspects of computer graphics: rendering, visualization and illustration in Axis 3, and editing and modeling (content creation) in Axis 4. In these two axes, the final observers are mainly human users, either generic users or expert ones (e.g., archaeologist [91], computer graphics artists).

3.3. Axis 1: Analysis and Simulation

Challenge: Definition and understanding of phenomena resulting from interactions between light, shape, and matter as seen from an observer point of view.

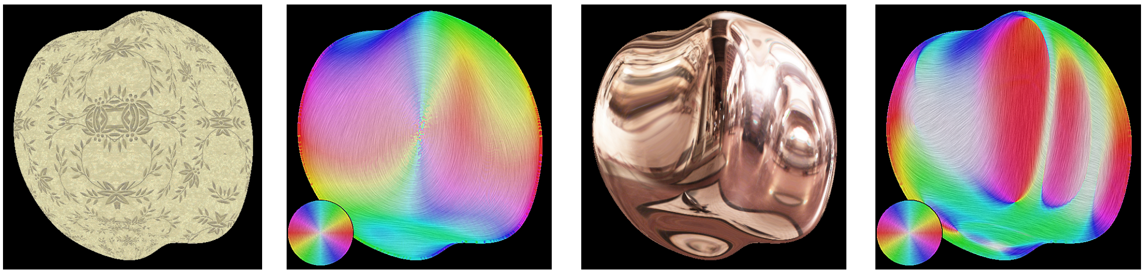
Results: Theoretical tools and numerical models for analyzing and simulating the observed optical phenomena.

To reach the goals of the *MANAO* project, we need to **increase our understanding** of how light, shape, and matter act together in synergy and how the resulting signal is finally observed. For this purpose, we need to identify the different phenomena that may be captured by the targeted observers. This is the main objective of this research axis, and it is achieved by using three approaches: the simulation of interactions between light, shape, and matter, their analysis and the development of new numerical models. This resulting improved knowledge is a foundation for the researches done in the three other axes, and the simulation tools together with the numerical models serve the development of the joint optical/digital systems in Axis 2 and their validation.

One of the main and earliest goals in computer graphics is to faithfully reproduce the real world, focusing mainly on light transport. Compared to researchers in physics, researchers in computer graphics rely on a subset of physical laws (mostly radiative transfer and geometric optics), and their main concern is to efficiently use the limited available computational resources while developing as fast as possible algorithms. For this purpose, a large set of tools has been introduced to take a **maximum benefit of hardware** specificities. These tools are often dedicated to specific phenomena (e.g., direct or indirect lighting, color bleeding, shadows, caustics). An efficiency-driven approach needs such a classification of light paths [58] in order to develop tailored strategies [104]. For instance, starting from simple direct lighting, more complex phenomena have been progressively introduced: first diffuse indirect illumination [56], [95], then more generic inter-reflections [65], [50] and volumetric scattering [92], [47]. Thanks to this search for efficiency and this classification, researchers in computer graphics have developed a now recognized expertise in fast-simulation of light propagation. Based on finite elements (radiosity techniques) or on unbiased Monte Carlo integration schemes (ray-tracing, particle-tracing, ...), the resulting algorithms and their combination are now sufficiently accurate to be used-back in physical simulations. The *MANAO* project will continue the search for **efficient and accurate simulation** techniques, but extending it from computer graphics to optics. Thanks to the close collaboration with scientific researchers from optics, new phenomena beyond radiative transfer and geometric optics will be explored.

Search for algorithmic efficiency and accuracy has to be done in parallel with **numerical models**. The goal of visual fidelity (generalized to accuracy from an observer point of view in the project) combined with the goal of efficiency leads to the development of alternative representations. For instance, common classical finite-element techniques compute only basis coefficients for each discretization element: the required discretization density would be too large and to computationally expensive to obtain detailed spatial variations and thus visual fidelity. Examples includes texture for decorrelating surface details from surface geometry and high-order wavelets for a multi-scale representation of lighting [46]. The numerical complexity explodes when considering directional properties of light transport such as radiance intensity (Watt per square meter and per steradian - $W.m^{-2}.sr^{-1}$), reducing the possibility to simulate or accurately represent some optical phenomena. For instance, Haar wavelets have been extended to the spherical domain [94] but are difficult to extend to non-piecewise-constant data [97]. More recently, researches prefer the use of Spherical Radial

Basis Functions [100] or Spherical Harmonics [85]. For more complex data, such as reflective properties (e.g., BRDF [79], [66] - 4D), ray-space (e.g., Light-Field [76] - 4D), spatially varying reflective properties (6D - [89]), new models, and representations are still investigated such as rational functions [82] or dedicated models [33] and parameterizations [93], [98]. For each (newly) defined phenomena, we thus explore the space of possible numerical representations to determine the **most suited one for a given application**, like we have done for BRDF [82].



Texuring 1st order gradient field Environment reflection 2st order gradient field

Figure 4. First-oder analysis [105] have shown that shading variations are caused by depth variations (first-order gradient field) and by normal variations (second-order fields). These fields are visualized using hue and saturation to indicate direction and magnitude of the flow respectively.

Before being able to simulate or to represent the different **observed phenomena**, we need to define and describe them. To understand the difference between an observed phenomenon and the classical light, shape, and matter decomposition, we can take the example of a highlight. Its observed shape (by a human user or a sensor) is the resulting process of the interaction of these three components, and can be simulated this way. However, this does not provide any intuitive understanding of their relative influence on the final shape: an artist will directly describe the resulting shape, and not each of the three properties. We thus want to decompose the observed signal into models for each scale that can be easily understandable, representable, and manipulable. For this purpose, we will rely on the **analysis** of the resulting interaction of light, shape, and matter as observed by a human or a physical sensor. We first consider this analysis from an **optical point of view**, trying to identify the different phenomena and their scale according to their mathematical properties (e.g., differential [86] and frequency analysis [52]). Such an approach has leaded us to exhibit the influence of surfaces flows (depth and normal gradients) into lighting pattern deformation (see Figure 4). For a **human observer**, this correspond to one recent trend in computer graphics that takes into account the human visual systems [53] both to evaluate the results and to guide the simulations.

3.4. Axis 2: From Acquisition to Display

Challenge: Convergence of optical and digital systems to blend real and virtual worlds.

Results: Instruments to acquire real world, to display virtual world, and to make both of them interact.

For this axis, we investigate *unified acquisition and display systems*, that is systems which combine optical instruments with digital processing. From digital to real, we investigate new display approaches [76], [61]. We consider projecting systems and surfaces [42], for personal use, virtual reality and augmented reality [36]. From the real world to the digital world, we favor direct measurements of parameters for models and representations, using (new) optical systems unless digitization is required [55], [54]. These resulting systems have to acquire the different phenomena described in Axis 1 and to display them, in an efficient manner [59], [34], [60], [63]. By efficient, we mean that we want to shorten the path between the real world and the virtual world by increasing the data bandwidth between the real (analog) and the virtual (digital) worlds, and

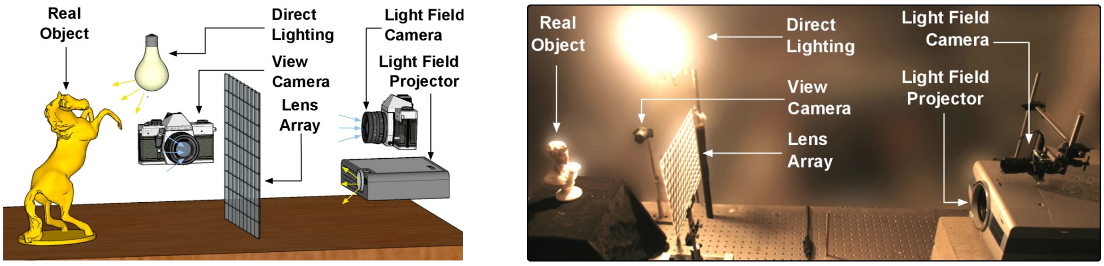


Figure 5. Light-Field transfer: global illumination between real and synthetic objects [45]

by reducing the latency for real-time interactions (we have to prevent unnecessary conversions, and to reduce processing time). To reach this goal, the systems have to be designed as a whole, not by a simple concatenation of optical systems and digital processes, nor by considering each component independently [64].

To increase data bandwidth, one solution is to **parallelize more and more the physical systems**. One possible solution is to multiply the number of simultaneous acquisitions (e.g., simultaneous images from multiple viewpoints [63], [84]). Similarly, increasing the number of viewpoints is a way toward the creation of full 3D displays [76]. However, full acquisition or display of 3D real environments theoretically requires a continuous field of viewpoints, leading to huge data size. Despite the current belief that the increase of computational power will fill the missing gap, when it comes to visual or physical realism, if you double the processing power, people may want four times more accuracy, thus increasing data size as well. Furthermore, this leads to solutions that are not energy efficient and thus cannot be embedded into mobile devices. To reach the best performances, a trade-off has to be found between the amount of data required to represent accurately the reality and the amount of required processing. This trade-off may be achieved using **compressive sensing**. Compressive sensing is a new trend issued from the applied mathematics community that provides tools to accurately reconstruct a signal from a small set of measurements assuming that it is sparse in a transform domain (e.g., [83], [108]).

We prefer to achieve this goal by avoiding as much as possible the classical approach where acquisition is followed by a fitting step: this requires in general a large amount of measurements and the fitting itself may consume consequently too much memory and preprocessing time. By **preventing unnecessary conversion** through fitting techniques, such an approach increase the speed and reduce the data transfer for acquisition but also for display. One of the best recent examples is the work of Cossairt et al. [45]. The whole system is designed around a unique representation of the energy-field issued from (or leaving) a 3D object, either virtual or real: the Light-Field. A Light-Field encodes the light emitted in any direction from any position on an object. It is acquired thanks to a lens-array that leads to the capture of, and projection from, multiple simultaneous viewpoints. A unique representation is used for all the steps of this system. Lens-arrays, parallax barriers, and coded-aperture [71] are one of the key technologies to develop such acquisition (e.g., Light-Field camera [1] [64] and acquisition of light-sources [55]), projection systems (e.g., auto-stereoscopic displays). Such an approach is versatile and may be applied to improve classical optical instruments [69]. More generally, by designing unified optical and digital systems [80], it is possible to leverage the requirement of processing power, the memory footprint, and the cost of optical instruments.

Those are only some examples of what we investigate. We also consider the following approaches to develop new unified systems. First, similar to (and based on) the analysis goal of Axis 1, we have to take into account as much as possible the characteristics of the measurement setup. For instance, when fitting cannot be avoided, integrating them may improve both the processing efficiency and accuracy [82]. Second, we have to integrate signals from multiple sensors (such as GPS, accelerometer, ...) to prevent some computation (e.g., [72]).

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[1] Lytro, http://www.lytro.com/

Finally, the experience of the group in surface modeling help the design of optical surfaces [67] for light sources or head-mounted displays.

3.5. Axis 3: Rendering, Visualization and Illustration

Challenge: How to offer the most legible signal to the final observer in real-time?

Results: High-level shading primitives, expressive rendering techniques for object depiction, real-time realistic rendering algorithms

(a) Global illumination [81] (b) Shadows [35] (c) Shape enhancement [10] (d) Shape depiction [32]

Figure 6. In the MANAO project, we are investigating rendering techniques from realistic solutions (e.g., inter-reflections (a) and shadows (b)) to more expressive ones (shape enhancement (c) with realistic style and shape depiction (d) with stylized style) for visualization.

The main goal of this axis is to offer to the final observer, in this case mostly a human user, the most legible signal in real-time. Thanks to the analysis and to the decomposition in different phenomena resulting from interactions between light, shape, and matter (Axis 1), and their perception, we can use them to convey essential information in the most pertinent way. Here, the word *pertinent* can take various forms depending on the application.

In the context of scientific illustration and visualization, we are primarily interested in tools to convey shape or material characteristics of objects in animated 3D scenes. **Expressive rendering** techniques (see Figure 6c,d) provide means for users to depict such features with their own style. To introduce our approach, we detail it from a shape-depiction point of view, domain where we have acquired a recognized expertise. Prior work in this area mostly focused on stylization primitives to achieve line-based rendering [106], [68] or stylized shading [40],[10] with various levels of abstraction. A clear representation of important 3D **object features** remains a major challenge for better shape depiction, stylization and abstraction purposes. Most existing representations provide only local properties (e.g., curvature), and thus lack characterization of broader shape features. To overcome this limitation, we are developing higher level descriptions of shape [31] with increased robustness to sparsity, noise, and outliers. This is achieved in close collaboration with Axis 1 by the use of higher-order local fitting methods, multi-scale analysis, and global regularization techniques. In order not to neglect the observer and the material characteristics of the objects, we couple this approach with an analysis of the appearance model. To our knowledge, this is an approach which has not been considered yet. This research direction is at the heart of the *MANAO* project, and has a strong connection with the analysis we plan to conduct in Axis 1. Material characteristics are always considered at the light ray level, but an understanding of **higher-level primitives** (like the shape of highlights and their motion) would help us to produce more legible renderings and permit novel stylizations; for instance, there is no method that is today able to create stylized renderings that follow the motion of highlights or shadows. We also believe such tools also play a fundamental role for geometry processing purposes (such as shape matching, reassembly, simplification), as well as for editing purposes as discussed in Axis 4.

In the context of **real-time photo-realistic rendering** ((see Figure 6a,b), the challenge is to compute the most plausible images with minimal effort. During the last decade, a lot of work has been devoted to design approximate but real-time rendering algorithms of complex lighting phenomena such as soft-shadows [107], motion blur [52], depth of field [96], reflexions, refractions, and inter-reflexions. For most of these effects it becomes harder to discover fundamentally new and faster methods. On the other hand, we believe that significant speedup can still be achieved through more clever use of **massively parallel architectures** of the current and upcoming hardware, and/or through more clever tuning of the current algorithms. In particular, regarding the second aspect, we remark that most of the proposed algorithms depend on several parameters which can be used to **trade the speed over the quality**. Significant speed-up could thus be achieved by identifying effects that would be masked or facilitated and thus devote appropriate computational resources to the rendering [70], [51]. Indeed, the algorithm parameters controlling the quality vs speed are numerous without a direct mapping between their values and their effect. Moreover, their ideal values vary over space and time, and to be effective such an auto-tuning mechanism has to be extremely fast such that its cost is largely compensated by its gain. We believe that our various work on the analysis of the appearance such as in Axis 1 could be beneficial for such purpose too.

Realistic and real-time rendering is closely related to Axis 2: real-time rendering is a requirement to close the loop between real world and digital world. We have to thus develop algorithms and rendering primitives that allow the integration of the acquired data into real-time techniques. We have also to take care of that these real-time techniques have to work with new display systems. For instance, stereo, and more generally multi-view displays are based on the multiplication of simultaneous images. Brute force solutions consist in independent rendering pipeline for each viewpoint. A more energy-efficient solution would take advantages of the computation parts that may be factorized. Another example is the rendering techniques based on image processing, such as our work on augmented reality [44]. Independent image processing for each viewpoint may disturb the feeling of depth by introducing inconsistent information in each images. Finally, more dedicated displays [61] would require new rendering pipelines.

3.6. Axis 4: Editing and Modeling

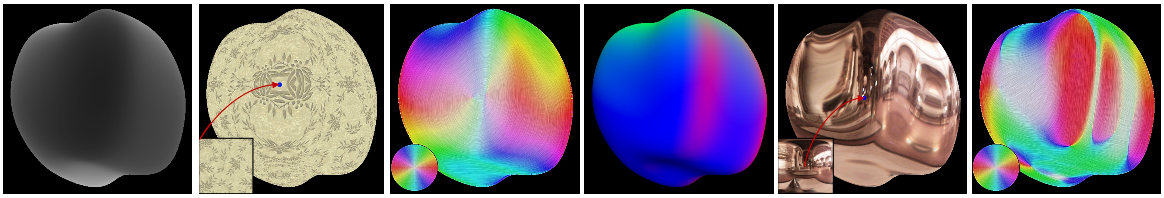
Challenge: Editing and modeling appearance using drawing- or sculpting-like tools through high level representations.

Results: High-level primitives and hybrid representations for appearance and shape.

During the last decade, the domain of computer graphics has exhibited tremendous improvements in image quality, both for 2D applications and 3D engines. This is mainly due to the availability of an ever increasing amount of shape details, and sophisticated appearance effects including complex lighting environments. Unfortunately, with such a growth in visual richness, even so-called *vectorial* representations (e.g., subdivision surfaces, Bézier curves, gradient meshes, etc.) become very dense and unmanageable for the end user who has to deal with a huge mass of control points, color labels, and other parameters. This is becoming a major challenge, with a necessity for novel representations. This Axis is thus complementary of Axis 3: the focus is the development of primitives that are easy to use for modeling and editing.

More specifically, we plan to investigate *vectorial representations* that would be amenable to the production of rich shapes with a minimal set of primitives and/or parameters. To this end we plan to build upon our insights on dynamic local reconstruction techniques and implicit surfaces [3] [39]. When working in 3D, an interesting approach to produce detailed shapes is by means of procedural geometry generation. For instance, many natural phenomena like waves or clouds may be modeled using a combination of procedural functions. Turning such functions into triangle meshes (main rendering primitives of GPUs) is a tedious process that appears not to be necessary with an adapted vectorial shape representation where one could directly turn procedural functions into implicit geometric primitives. Since we want to prevent unnecessary conversions in the whole pipeline (here, between modeling and rendering steps), we will also consider *hybrid representations* mixing meshes and implicit representations. Such research has thus to be conducted while considering the associated editing tools as well as performance issues. It is indeed important to keep *real-time performance* (cf. Axis 2) throughout the interaction loop, from user inputs to display, via editing and rendering operations. Finally, it would be interesting to add *semantic information* into 2D or 3D geometric representations. Semantic geometry appears to be particularly useful for many applications such as the design of more efficient manipulation and animation tools, for automatic simplification and abstraction, or even for automatic indexing and searching. This constitutes a complementary but longer term research direction.

In the *MANAO* project, we want to investigate representations beyond the classical light, shape, and matter decomposition. We thus want to directly control the appearance of objects both in 2D and 3D applications (e.g., [102]): this is a core topic of computer graphics. When working with 2D vector graphics, digital artists must carefully set up color gradients and textures: examples range from the creation of 2D logos to the photo-realistic imitation of object materials. Classic vector primitives quickly become impractical for creating illusions of complex materials and illuminations, and as a result an increasing amount of time and skill is required. This is only for still images. For animations, vector graphics are only used to create legible appearances composed of simple lines and color gradients. There is thus a need for more complex primitives that are able to accommodate complex reflection or texture patterns, while keeping the ease of use of vector graphics. For instance, instead of drawing color gradients directly, it is more advantageous to draw flow lines that represent local surface concavities and convexities. Going through such an intermediate structure then allows to deform simple material gradients and textures in a coherent way (see Figure 7), and animate them all at once. The manipulation of 3D object materials also raises important issues. Most existing material models are tailored to faithfully reproduce physical behaviors, not to be *easily controllable* by artists. Therefore artists learn to tweak model parameters to satisfy the needs of a particular shading appearance, which can quickly become cumbersome as the complexity of a 3D scene increases. We believe that an alternative approach is required, whereby material appearance of an object in a typical lighting environment is directly input (e.g., painted or drawn), and adapted to match a plausible material behavior. This way, artists will be able to create their own appearance (e.g., by using our shading primitives [102]), and replicate it to novel illumination environments and 3D models. For this purpose, we will rely on the decompositions and tools issued from Axis 1.



(a) (b) (c) (d) (e) (f)

Figure 7. Based on our analysis [105] (Axis 1), we have designed a system that mimics texture (left) and shading (right) effects using image processing alone. It takes depth (a) and normal (d) images as input, and uses them to deform images (b-e) in ways that closely approximate surface flows (c-f). It provides a convincing, yet artistically controllable illusion of 3D shape conveyed through texture or shading cues.

4. New Software and Platforms

4.1. Software

4.1.1. ALTA Library

Participants: X. Granier & R. Pacanowski & L. Belcour & P. Barla

Keywords: BRDF fitting and analysis
ALTA is a multi-platform software library to analyze, fit and understand BRDFs. It provides a set of command line software to fit measured data to analytical forms, and tools to understand models and data. The targeted audience is composed of all the researchers and professionals who are working on BRDFs, and who want to benchmark new BRDF models and easily compare them with state-of-the-art BRDF models and data. It is also suitable for researchers and professionals who are working on optical measurements, and who want to experiment different fitting procedures and models, or just to perform statistical analysis on their data. The major features in the ALTA library are:

- Open common BRDF data formats (MERL, ASTM)
- Non-linear fitting of BRDF (using third party packages)
- Rational interpolation of BRDF
- Analytic BRDF models
- Scripting mechanism to automatize fitting

ALTA has been supported by the ANR ALTA (ANR-11-BS02-006).
Facts:

- Web: http://alta.gforge.inria.fr/
- License: MPLv2

4.1.2. Eigen

Participants: G. Guennebaud
Keywords: Linear algebra
Efficient numerical computation is central to many computer science domains. In particular, in computer graphics, space transformations and local regressions involve dense linear algebra, data interpolation and differential equations require sparse linear algebra, while more advanced problems involve non-linear optimization or spectral analysis. On the one hand, solutions such as MatLab are limited to prototyping. On the other hand, optimized libraries coming from the HPC (high performance computing) world are often tedious to use and more adapted for very large problems running on clusters. Moreover, all these solutions are very slow at handling very small but numerous problems which often arise in computer graphics, vision, or robotics. As a result, researchers of these domains used to waste a lot of time at either implementing their own half cooked solution, or dealing with dozens of complex to use libraries.

The objective of Eigen is to fill this gap by proposing an easy to use, efficient, and versatile C++ mathematical template library for linear algebra and related algorithms. In particular it provides fixed and dynamic size matrices and vectors, matrix decompositions (LU, LLT, LDLT, QR, eigenvalues, etc.), sparse matrices with iterative and direct solvers, some basic geometry features (transformations, quaternions, axis-angles, Euler angles, hyperplanes, lines, etc.), some non-linear solvers, automatic differentiations, etc. Thanks to expression templates, Eigen provides a very powerful and easy to use API. Explicit vectorization is performed for the SSE, AltiVec and ARM NEON instruction sets, with graceful fallback to non-vectorized code. Expression templates allow to perform global expression optimizations, and to remove unnecessary temporary objects.

Eigen is already a well established library with about 30k unique visitors of the website per month. Eigen is co-developed and maintained with a couple of other researchers and occasional contributors spread over the world. Its development started in 2008, and the last release is the 3.2 version in July 2013. Eigen has been supported by Inria through an ADT started in January 2012, and that ended in September 2013. Eigen received the **"high-quality software in geometry processing award"** from the Symposium on Geometry Processing 2013. Eigen is continuously and actively developed with this year an important refactoring of the expression evaluation mechanism, a divide & conquer SVD algorithm, support for AVX in collaboration with Google, and many other features.
Facts:

- Web: http://eigen.tuxfamily.org/
- License: MPLv2

4.1.3. PatateLib

Participants: N. Mellado, G. Ciaudo, S. Boyé, G. Guennebaud, P. Barla

Keywords: multi-scale analysis, material appearance, vector graphics, expressive rendering, 2D animation

Patate is a header only C++/CUDA library for graphics applications released under the MPL license.

It provides a collection of Computer Graphics techniques that incorporate the latest innovations from Inria research teams working in the field. It strives for efficiency and ease-of-use by focusing on low-level core operators and key algorithms, organized in modules, each tackling a specific set of issues. The central goal of the library is to drastically reduce the time and efforts required to turn a research paper into a ready-to-use solution, for both commercial and academic purposes.

Each module is initially developed by a few persons, usually those who have authored the corresponding research papers. An engineer, Gautier Ciaudo, has been recruited via the ADT program to perform unit tests, bug tracking, and make examples. Our first module provides efficient methods for the fitting and analysis of point-clouds in arbitrary dimensions. It may be used for varied purposes such as curvature computation, surface reconstruction, scale-space analysis, image processing, and sketch vectorization. More modules will be developed in 2015 by Simon Boyé.

Facts:

- Web: http://patate.gforge.inria.fr
- License: MPLv2

4.1.4. PFSTools

Participant: I. Ihrke

Keywords: high dynamic range image processing, merging, calibration and tone-mapping

The `pfstools` package is a set of command line programs for reading, writing, manipulating and viewing high-dynamic range (HDR) images and video frames. All programs in the package exchange data using a simple generic high dynamic range image format, `pfs`, and they use unix pipes to pass data between programs and to construct complex image processing operations.

`pfstools` come with a library for reading and writing pfs files. The library can be used for writing custom applications that can integrate with the existing `pfstools` programs. It also offers a good integration with high-level mathematical programming languages, such as MATLAB or GNU Octave. `pfstools` can be used as an extension for MATLAB or Octave for reading and writing HDR images or simply to effectively store large matrices. The `pfstools` package integrates existing high dynamic range image formats by providing a simple data format that can be used to exchange data between applications. It is accompanied by the `pfscalibration` and `pfstmo` packages.

The `pfscalibration` package provides algorithms for the photometric calibration of cameras and for the recovery of high dynamic range (HDR) images from a set of low dynamic range (LDR) exposures. Maintenance of the pfscalibration package is performed by Ivo Ihrke since January 2011. A major update to make the software compatible with current digital SLR cameras and their raw file formats, especially for measurement purposes, has been performed. A new set of MATLAB scripts has been developed for improved calibration performance. It is intended to merge these new procedures into the existing software.

The `pfstmo` package contains the implementation of seven state-of-the-art tone mapping operators suitable for convenient processing of both static images and animations.

The software received wider interest in the Open Source community and third party contributors prepared installation packages which are included in several Linux distributions including Debian, Fedora and Suse.

Facts:

- Web: http://pfstools.sourceforge.net/
- License: GPL

4.2. Platforms

4.2.1. COEL - Computational Optics Experimentation Laboratory

We are setting a dedicated experimentation facility up to validate our theoretical tools to design hybrid (optics & computer sciences) systems by creating real setups. Such a facility is unique thanks to the close collaboration between optics and computer science in Bordeaux. Now located in the LP2N, this laboratory consists in a set of on-the-shell elements to design optical systems combined with controllable large-band lighting systems (from pure white sources, to tunable lasers and video-projectors), with a fabrication laboratory to build non-conventional components, with large-scale mechanical elements, with display technologies, and high-performance processing resources.

After initial delays, the lab has now found its final location in LP2N. The basic equipment is in place and first experiments are being performed. We still have to work on the illumination conditions in the room, as well as on the construction of a light-sealed control area inside the experimentation room for independent experiments.

The construction and equipment is financed by a special regional grant of the "Conseil Régional d'Acquitaine" (Carer xD) in conjunction with project-specific funds.

5. New Results

5.1. Highlights of the Year

We are still developping our expertise in fitting techniques. As an illustration, we have solved of a long-standing problem in fluid capture: the non-invasive three-dimensional digitization of dynamic gas flows *including their three-dimensional velocity fields* [17] (cf. Figure 8). We solve the three-dimensional flow tracking problem by fitting a full 3D Navier-Stokes simulation to the acquired data. To our knowledge, this is a world-first in this area that considerably improves the results by incorporating high-level prior knowledge into the estimate. The resulting mathematical framework can be generalized easily and lends itself to editing operations. The technique has applications, e.g., in aerospace engineering. We are exploring the possibilities with ONERA, the French space agency. In fact, parts of the developed techniques have been validated by them and are now being installed in a wind tunnel facility for real-world tests.

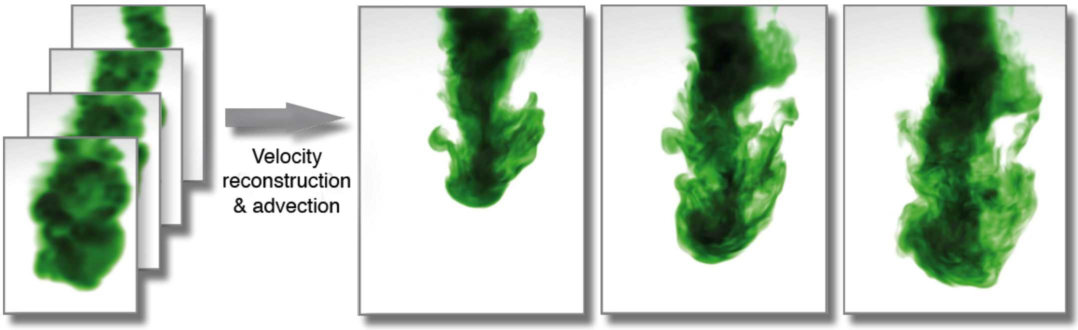


Figure 8. Low-resolution captures obtained by tomographic scanning (left) are used as inputs to our method which estimates physically plausible dense velocity fields. Such velocity fields fully determine the fluid state and can be applied in a variety of applications including fluid super-resolution (right) allowing capture to be integrated into pipelines for visual effects simulation.

This year, the collaboration between Optics and Computer Graphics has grown to a now long-term project, under the initiative of the MANAO team. First, from an institutional point of view, a framework agreement has been signed the 10th of July 2014 between the IOGS and Inria. This is an important and institutional recognition of the potential trans-disciplinary impacts of our work. Second, we have begun to set-up the COEL experimentation facility inside the LP2N laboratory. It has been made possible thanks to the support of the "Région Aquitaine" and upcoming supports from l'"Initiative d'excellence de l'université de Bordeaux". With this trans-disciplinary experimentation facility – rather unique in Europe – we can now put into practice a long-term vision of the researches that we want to achieve.

In term of visibility, we managed to published our first paper in the Optics scientific community [15], highlighting our trans-disciplinary research. We have also been part of the final and transnational exhibition of the V-Must.net network of excellence: Keys2Rome - http://keys2rome.eu. It was launched simultaneously in Rome, Sarajevo, Amsterdam and Alexandria on September 23, 2014. The exhibition uses immersive technology to present and connect these regional cultures within the Roman Empire, highlighting their diversity and commonality over centuries of Roman rule. Our spatial augmented reality solution [21] was included in this event.

5.2. Analysis and Simulation

5.2.1. Importance Sampling of Realistic Light Sources

Realistic images can be rendered by simulating light transport with Monte Carlo methods. The possibility to use realistic light sources for synthesizing images greatly contributes to their physical realism. Among existing models, the ones based on environment maps and light fields are attractive due to their ability to capture faithfully the far-field and near-field effects as well as their possibility of being acquired directly. Since acquired light sources have arbitrary frequencies and possibly high dimensions (4D), using such light sources for realistic rendering leads to performance problems. We have investigated [12] how to balance the accuracy of the representation and the efficiency of the simulation (cf. Figure 9). The work relies on generating high quality samples from the input light sources for unbiased Monte Carlo estimation [74]. This is a foundation work that has leaded to new sampling techniques for physically-based rendering with time-varying environment lighting [73] and light field light sources. The results show that physically accurate rendering with realistic light sources can be achieved in real time.

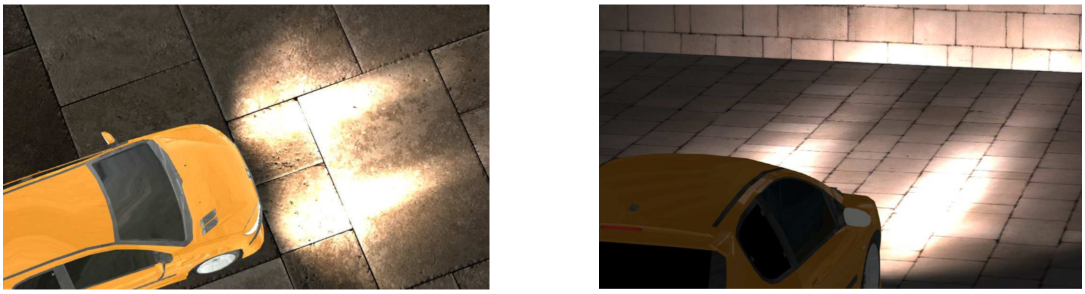


Figure 9. Our new light importance sampling technique estimates direct lighting interactively (7-9 fps) with only 200 samples per pixel that are distributed among the different images of the light field luminaire. The car headlights are represented by the same light field composed of 11 × 9 images (256 × 256 pixels).

5.2.2. Frequency Analysis of Light Scattering and Absorption

We have proposed [14] an innovative analysis of absorption and scattering of local light fields in the Fourier domain, and derived the corresponding set of operators on the covariance matrix of the power spectrum of the light field. This analysis brings an efficient prediction tool for the behavior of light along a light path in participating media. We leverage this analysis to derive proper frequency prediction metrics in 3D by combining per-light path information in the volume. Our key contribution is to show that analyzing local light fields in the Fourier domain reveals the consistency of illumination in such media, and provides a set of simple and useful rules to be used to accelerate existing global illumination methods.

5.3. Acquisition and Display

5.3.1. Three-Dimensional, Dynamic, Full State Fluid Capture and Manipulation

Participant: I. Ihrke

We have explored [17] the connection between fluid capture, simulation and proximal methods, a class of algorithms commonly used for inverse problems in image processing and computer vision. Our key finding is that the proximal operator constraining fluid velocities to be divergence-free is directly equivalent to the pressure-projection methods commonly used in incompressible flow solvers. This observation lets us treat the inverse problem of fluid tracking as a constrained flow problem all while working in an efficient, modular framework. In addition it lets us tightly couple fluid simulation into flow tracking, providing a global prior that significantly increases tracking accuracy and temporal coherence as compared to previous techniques. We demonstrate how we can use these improved results for a variety of applications, such as re-simulation, detail enhancement, and domain modification. We furthermore give an outlook of the applications beyond fluid tracking that our proximal operator framework could enable by exploring the connection of deblurring and fluid guiding.

5.3.2. Measurements and Analysis of Retro-reflective Materials

Participants: L. Belcour, R. Pacanowski

We have compared [15] performance of various analytical retro-reflecting BRDF models to assess how they reproduce accurately measured data of retro-reflecting materials. We have also introduced a new parametrization, the back vector parametrization, to analyze retro-reflecting data and we have shown that this parametrization better preserves the isotropy of data. Furthermore, we have updated existing BRDF models to improve the representation of retro-reflective data. This work was supported by the development of the ALTA library [23].

5.3.3. Kaleidoscopic Imaging

Participants: I. Reshetouski, I. Ihrke

Kaleidoscopes have a great potential in computational photography as a tool for redistributing light rays. In time-of-flight imaging the concept of the kaleidoscope is also useful when dealing with the reconstruction of the geometry that causes multiple reflections. Our work [13] is a step towards opening new possibilities for the use of mirror systems as well as towards making their use more practical. The focus of this work is the analysis of planar kaleidoscope systems to enable their practical applicability in 3D imaging tasks. We have analyzed important practical properties of mirror systems and developed a theoretical toolbox for dealing with planar kaleidoscopes. Based on this theoretical toolbox, we have explored the use of planar kaleidoscopes for multi-view imaging and for the acquisition of 3D objects [90]. The knowledge of the mirrors positions is crucial for these multi-view applications. On the other hand, the reconstruction of the geometry of a mirror room from time-of-flight measurements is also an important problem. We therefore employ the developed tools for solving this problem using multiple observations of a single scene point.

5.3.4. Interactive Spatial Augmented Reality

Participants: B. Ridel, P. Reuter, X. Granier

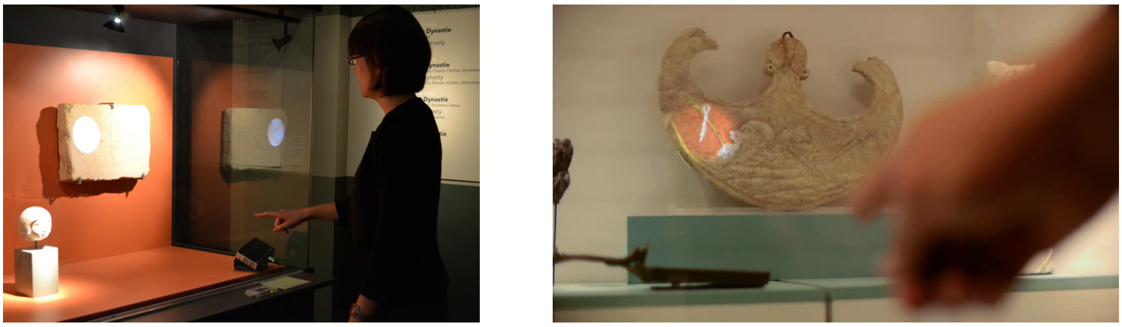


Figure 10. "The Revealing Flashlight" lets visitors explore ancient artifacts interactively. (Left) Allard Pierson Museum - Amsterdam. (Right) Keys2Rome exhibition in Museo dei Fori Imperiali - Roma.

We have proposed the *Revealing Flashlight* [21], a new 6-degree-of-freedom interaction and visualization technique in spatial augmented reality that helps to reveal the details of cultural heritage artifacts. We locally and interactively highlight them by projecting an expressive visualization. The Revealing Flashlight can be used by archaeologists, for example, to help decipher inscriptions in eroded stones, or by museums (cf. Figure 10) to let visitors interactively discover the features and meta-information of cultural artifacts. A permanent exhibition is now running at the Allard Pierson Museum, and others museums are asking us to set-up similar installations. It was part of the final trans-European showcase of the V-MusT.net project.

5.4. Rendering, Visualization & Illustration

5.4.1. Computing Smooth Surface Contours with Accurate Topology

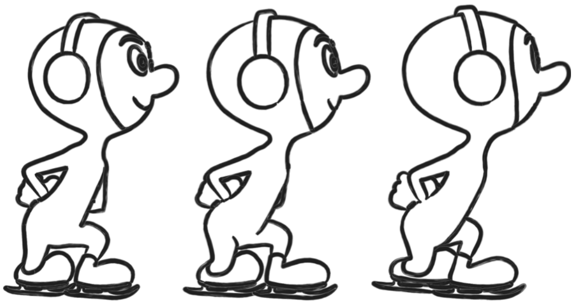


Figure 11. Contours stylized with tapered strokes [16]. Our method avoids classical breaks and gaps, producing more coherent animated strokes. Red © Pixar

We have introduced [16] a method for accurately computing the visible contours of a smooth 3D surface for stylization. This is a surprisingly difficult problem, and previous methods are prone to topological errors, such as gaps in the outline. Our approach is to generate, for each viewpoint, a new triangle mesh with contours that are topologically-equivalent and geometrically close to those of the original smooth surface. The contours of the mesh can then be rendered with exact visibility. The core of the approach is Contour-Consistency, a way to prove topological equivalence between the contours of two surfaces. Producing a surface tessellation that satisfies this property is itself challenging; to this end, we introduce a type of triangle that ensures consistency at the contour. We then introduce an iterative mesh generation procedure, based on these ideas. This procedure does not fully guarantee consistency, but errors are not noticeable in our experiments. Our algorithm can operate on any smooth input surface representation; we use Catmull-Clark subdivision surfaces in our implementation.

5.5. Editing and Modeling

5.5.1. *Tomography-Based Volume Painting*

Participant: I. Ihrke

Although volumetric phenomena are important for realistic rendering and can even be a crucial component in the image, the artistic control of the volume's appearance is challenging. Appropriate tools to edit volume properties are missing, which can make it necessary to use simulation results directly. Alternatively, high-level modifications that are rarely intuitive, e.g., the tweaking of noise function parameters, can be utilized. We have introduced [18] a solution to stylize single-scattering volumetric effects in static volumes. Hereby, an artistic and intuitive control of emission, scattering and extinction becomes possible, while ensuring a smooth and coherent appearance when changing the viewpoint. Our method is based on tomographic reconstruction, which we link to the volumetric rendering equation. It analyzes a number of target views provided by the artist and adapts the volume properties to match the appearance for the given perspectives. Additionally, we describe how we can optimize for the environmental lighting to match a desired scene appearance, while keeping volume properties constant. Finally, both techniques can be combined. We demonstrate several use cases of our approach and illustrate its effectiveness.

5.5.2. *Implicit Skinning*

Participant: G. Guennebaud

In collaboration with IRIT (Toulouse), we extended our *implicit skinning* method to a new approach for interactive character skinning called *elastic implicit skinning*. The method simulates skin contacts between limbs as well as the effect of skin elasticity (Figure 12). In addition, we go a step further towards the automation of the rigging process: our method doesn't require the definition of skinning weights. Elastic implicit skinning takes the best features of the recent implicit skinning method, and makes it robust to extreme character movements. While keeping the idea of implicit skinning, namely approximate the character by 3D scalar fields in which mesh-vertices are appropriately re-projected, we depart from the processing pipeline used so far. Implicit skinning is history independent and uses an initial skinning solution (e.g., linear blending or dual quaternions) to correct vertex positions at each frame. Our new approach is history dependent; the mesh directly tracks the iso-surfaces of the scalar field over time. Technically our solutions include: new implicit surface composition operators and a tangential relaxation scheme derived from the as-rigid-as possible energy. This work [101] has been presented at SIGGRAPH Asia this year.

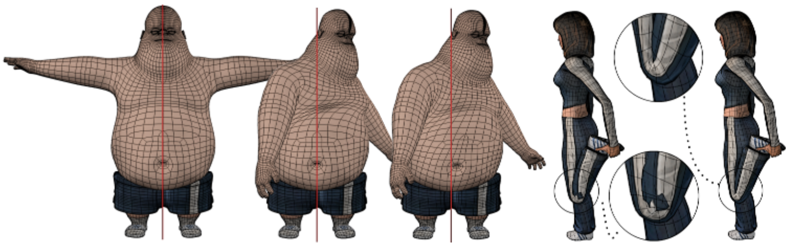


Figure 12. Illustration of the benefits of our novel elastic implicit skinning technique.

5.5.3. Multi-scale Editing

Participant: G. Guennebaud

In the continuation of our Growing Least Square approach [5] for the multi-scale analysis of shape, we developed a novel tool that enables the direct editing of surface features in large point-clouds or meshes [19]. This is made possible by a novel multi-scale analysis of unstructured point-clouds that automatically extracts the number of relevant features together with their respective scale all over the surface. Then, combining this ingredient with an adequate multi-scale decomposition allows us to directly enhance or reduce each feature in an independent manner. Our feature extraction is based on the analysis of the scale-variations of locally fitted surface primitives combined with unsupervised learning techniques. Our tool may be applied either globally or locally, and millions of points are handled in real-time. The resulting system enables users to accurately edit complex geometries with minimal interaction.

5.5.4. Manipulation of Anisotropic Highlights

Participants: B. Raymond, P. Barla, G. Guennebaud, X. Granier

We have developed [20] a system for the direct editing of highlights produced by anisotropic BRDFs, which we call anisotropic highlights. We first provide a comprehensive analysis of the link between the direction of anisotropy and the shape of highlight curves for arbitrary object surfaces. The gained insights provide the required ingredients to infer BRDF orientations from a prescribed highlight tangent field. This amounts to a non-linear optimization problem, which is solved at interactive framerates during manipulation. Taking inspiration from sculpting software, we provide tools that give the impression of manipulating highlight curves while actually modifying their tangents. Our solver produces desired highlight shapes for a host of lighting environments and anisotropic BRDFs.

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contracts with Industry

- CIFRE PhD contract with Technicolor 2 (2014-2018)
  Participants: A. Dufay, X. Granier, and R. Pacanowski
  For this project, we aim at providing interactive previsualization of complex lighting with a smooth transition to the final solution.

7. Partnerships and Cooperations

7.1. Regional Initiatives

7.1.1. Carer xD: "Caractérisation et restitution du réel xD"

Currently, the characterization and display of the real world are limited to techniques focusing on a subset of the necessary physical phenomena. A lot of work has been done to acquire geometric properties. However, the acquisition of a geometry on an object with complex reflection property or dynamic behavior is still a challenge. Similarly, the characterization of a material is limited to a uniform object for complex material or a diffuse material when one is interested in its spatial variations.

To reach full interaction between real and virtual worlds (augmented reality, mixed reality), it is necessary to acquire the real world in all its aspects (spatial, spectral, temporal) and to return it as in all these dimensions. To achieve this goal, a number of theoretical and practical tools will be developed around the development of mixed reality solutions and the development of some theoretical framework that supports the entire project.

7.2. National Initiatives

7.2.1. ANR

7.2.1.1. *"Young Researcher" RichShape (2014-2018):*

MANAO
Leader: G. Guennebaud
This project aims at the development of novel representations for the efficient rendering and manipulation of highly detailed shapes in a multi-resolution context.

7.2.1.2. *ALTA (2011-2015):*

MAVERICK, REVES
Leader: N. Holzschuch (MAVERICK)
The project ALTA aims at analyzing the light transport equations and at using the resulting representations and algorithms for more efficient computation. We target lighting simulations, either off-line, high-quality simulations or interactive simulations.

7.2.1.3. *"Young Researcher" IM&M (2011-2015):*

IRIT
Leader: L. Barthe (IRIT)
This project aims at the definition of simple and robust tools for the modeling of 3D objects. To this end, the proposed approach consists in combining the nice mathematical properties of implicit surfaces with classical meshes.

7.2.2. Competitivity Clusters

7.2.2.1. *LabEx CPU:*

IMB (UPR 5251), LABRI (UMR 5800), Inria (CENTRE BORDEAUX SUD-OUEST), I2M (NEW UMR FROM 2011), IMS (UMR 5218), CEA/DAM
Some members of *MANAO* participate in the local initiative CPU. As it includes many thematics, from fluid mechanics computation to structure safety but also management of timetable, safety of networks and protocols, management of energy consumption, etc., numerical technology can impact a whole industrial sector. In order to address problems in the domain of certification or qualification, we want to develop numerical sciences at such a level that it can be used as a certification tool.

7.3. European Initiatives

7.3.1. FP7 & H2020 Projects

7.3.1.1. *FP7 NoE - V-MusT.net (2011-2015):*

Participants: cf. http://www.v-must.net/participants
Leader: S. Pescarin (CNR - Italy)
V-MusT.net is a European Network of Excellence dedicated to Virtual Museums. A Virtual Museum is a personalized, immersive, interactive experience that aims to enhance our understanding of the past in museums or on the Internet. The V-Must.net network enables heritage professionals around the world to connect, collaborate and advance the development and use of virtual museums.

7.3.1.2. *FP7 ITN - PRISM "Perceptual Representations for Illumination, Shape and Materials" (2013-2016):*

Participants: Giessen University, Université Paris-Descartes, Bilkent University, Université de Leuven, Delft University, Birmingham University, Philips and NextLimit
Leader: R. Fleming (Giessen University)

The goal of this project is to better understand how the human visual system understands images in terms of meaningful components: How is shape perceived consistently in varying illumination conditions and for different materials? To which extent are humans able to guess the main illumination directions in a scene? What visual properties do we make use of to estimate the material an object is made of without touching it? Answering these questions will require inter-disciplinary research and collaborations.

7.3.2. Foreign grants

7.3.2.1. DFG Emmy-Noether grant “Plenoptic Acquisition and Projection - Theoretical Developments and Applications” (2012-2017)

Leader: I. Ihrke

This project aims to develop a comprehensive theory of the imaging process in optical-computational devices as developed in the newly emerging field of Computational Optics. The theory will be validated by a number of practical applications.

It will allow for the modeling of image formation processes in measurement systems employing novel computational imaging and projection devices. This makes it possible to optimize these systems with respect to particular imaging tasks, which is currently impossible due to limited models. A further interesting aspect of the project is that computational imaging devices will become comparable with respect to parameters such as their resolution and noise characteristics which is hardly possible at the moment.

7.4. International Research Visitors

7.4.1. Visits of International Scientists

7.4.1.1. From University of Montréal

Since the summer 2014, we are welcoming in our team Dr. Laurent BELCOUR, a post-doc from the University of Montréal. We are working together on the development of theoretical and practical tools for the analysis and the modeling of light transport operators such as BRDFs [15], [23].

7.4.1.2. From Beijing Normal University

We have long-standing exchanges with the Beijing Normal University. This university is in charge of some virtual reconstruction of the Chinese Cultural Heritage (such as the terracota warrios and the old Beijing). In this context, we received Dr. SHUI Wuyang for a one month visit in February to work on the use of our results to help the reconstruction and the visualization of ancient artefacts.

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific events selection

8.1.1.1. member of the conference program committee

Expressive 2014 (NPAR-SBIM-CAe), Eurographics 2014, SIGGRAPH Asia Tech Brief & Posters 2014 CVPR 2014, ECCV 2014, Light Fields for Computer Vision 2014, Computational Cameras and Displays 2014, SPIE Photonics Asia 2014, International Conference on Computational Photography 2014, Pacific Graphics 2014

8.1.1.2. reviewer

ACM SIGGRAPH 2014, ACM SIGGRAPH Asia 2014, Eurographics 2015, Eurographics Symposium on Rendering 2014, Pacific Graphics 2014, ACM User Interface Software and Technology Symposium 2014

8.1.2. Journal

8.1.2.1. reviewer

ACM Transaction on Graphics (TOG), Computer Graphics Forum (CGF), Transactions on Visualization and Computer Graphics (TVCG), Computer & Graphics, Journal of Vision (JoV), SIAM Journal on Scientific Computing, Transactions on Pattern Analysis and Machine Intelligence (TPAMI), Applied Optics, Optics Letters, REFIG, Journal of Computer Science and Technology (JCST), Journal of Zhejiang University Science C (ZUSC)

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

The members of our team are involved in teaching computer science at University of Bordeaux, ENSEIRB Engineering School, and Institut d'Optique Graduate School (IOGS). General computer science is concerned, as well as the following graphics related topics:

Master : Pierre Bénard and Romain Pacanowski, Photorealistic and Expressive Image Synthesis, 60 HETD, M2, Univ. Bdx, France.

Master : Xavier Granier, Numerical Techniques, 45 HETD, M1, IOGS, France

Master : Xavier Granier, Image Synthesis, 14 HETD, M2, IOGS, France

Master : Gaël Guennebaud, Geometric Modeling, 22 HETD, M2, IOGS, France

Master : Xavier Granier, Romain Pacanowski, Boris Raymond Brett Ridel, Algorithmic and Object Programming, 60 HETD, M1, IOGS, France

Master : Xavier Granier, Radiometry, 10 HETD, M1, IOGS, France

Master : Gaël Guennebaud and Pierre Bénard, High-performance 3D Graphics, 60 HETD, M1, Univ. Bdx and IOGS, France.

Master : Pascal Guitton and Pierre Bénard, Virtual Reality, 60 HETD, M2, Univ. Bdx, France.

Master : Ivo Ihrke, Computational Optical Imaging, 30 HETD, M1, IOGS, France

Master : Ivo Ihrke, Introduction to Image Processing, 30 HETD, M1, IOGS, France

Master : Ivo Ihrke, Advanced Display Technology, 12 HETD, M1, IOGS, France

Master : Christophe Schlick, Pierre Bénard, Image Synthesis, 60 HETD, M2, ENSEIRB, France

Licence : Patrick Reuter, Digital Imaging, 36 HETD, L3, Univ. Bdx, France.

Some members are also in charge of some fields of study:

Master : Xavier Granier, Optics and Computer Science, M1/M2, IOGS, France.

License : Patrick Reuter, Science and Modeling, L2, Univ. Bdx, France.

8.2.2. Supervision

PhD : Cyprien Buron, Interactive Generation and Rendering of Massice Models: a Parallel Procedural Approach, Univ. Bordeaux, 4th of February 2014, J.-E. Marvie & G. Guennebaud & X. Granier

PhD : Heqi Lu, Importance Sampling of Realistic Light Sources, Univ. Bordeaux, 27th of February 2014, X. Granier & R. Pacanowski

PhD : Ilya Reshetouski, Kaleidoscipic Imaging, Saarland University, 6th of November 2014, I. Ihrke

PhD : Alkhazur Manakov, Calibration and Characterization of Advanced Image-Based Measurement Systems, Saarland University, I. Ihrke

PhD : Boris Raymond, Rendering and manipulation of anisotropic materials, Univ. Bordeaux, P. Barla & G. Guennebaud & X. Granier

PhD : John Restrepo, Plenoptic Imaging and Computational Image Quality Metrics, Univ. Bordeaux, I. Ihrke

PhD : Brett Ridel, Interactive spatial augmented reality, Univ. Bordeaux, P. Reuter & X. Granier

PhD : Carlos Zubiaga Pena, Image-space editing of appearance, Univ. Bordeaux, P. Barla & X. Granier

PhD : Florian Canezin, Implicit Modeling, Univ. Toulouse III, G. Guennebaud & Loïc Barthe

PhD : Mathieu Diawara, Computer-Assisted 2D Animation, Univ. Bordeaux, P. Barla, P. Bénard & X. Granier

PhD : Arthur Dufay, Adaptive high-quality of virtual environments with complex photometry, Univ. Bordeaux, J.-E. Marvie R. Pacanowski & X. Granier

PhD : Thibaud Lambert, Real-time rendering of highly detailed 3D models, Univ. Bordeaux, G. Guennebaud & P. Bénard

PhD : Loïs Mignard-Debize, Plenoptic function and its application to spatial augmented reality, Univ. Bordeaux, P. Reuter & I. Ihrke

8.2.3. Juries

PhD : Guillaume Bouchard [37], 23th of May, Lyon, France.

9. Bibliography

Major publications by the team in recent years

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[2] P. BÉNARD, A. HERTZMANN, M. KASS. *Computing Smooth Surface Contours with Accurate Topology*, in "ACM Transactions on Graphics", 2014, http://hal.inria.fr/hal-00924273

[3] J. CHEN, G. GUENNEBAUD, P. BARLA, X. GRANIER. *Non-oriented MLS Gradient Fields*, in "Computer Graphics Forum", December 2013, http://hal.inria.fr/hal-00857265

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Doctoral Dissertations and Habilitation Theses

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