Activity Report 2013

Team MANAO

Melting the frontiers between Light, Shape and Matter

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Interaction and visualization

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Team MANAO

Keywords: Computer Graphics, 3d Modeling, Geometry Modeling, Rendering, Augmented Reality, Virtual Reality

The MANAO project is a joined project between CNRS, Inria, Institut d'Optique Graduate School (IOGS) and, University of Bordeaux. The project is working with two laboratories: LaBRI and LP2N.

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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 [64], [42] 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 [74] and Light-Field rendering [40]). 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 [72], [75], 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 [96] 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
[56]

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 [85], stereo displays or new display technologies [60], and physical fabrication [30], [48], [56]) the frontiers between real and virtual worlds are vanishing [44]. 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

2.2.1. Methodology

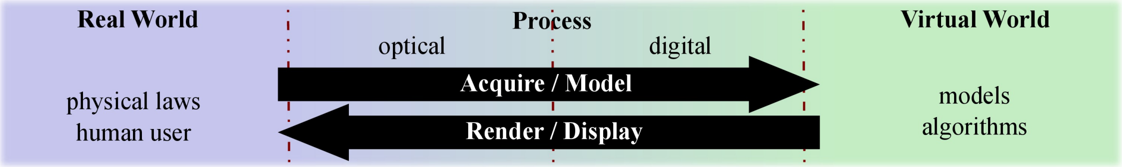


Figure 2. Interactions/Transfers between real and virtual worlds. One of our goal is to combine optical instruments with processes from computer science in order to blend the two worlds.

2.2.1.1. 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 [8], as mastered by professional photographers;
- The modification of material characteristics or lighting conditions [9] to better understand shape features, for instance to decipher archaeological artifacts;
- The large influence of shape on the captured variation of shading [83] and thus on the perception of material properties [99].

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) [47] 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.

2.2.1.2. *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 [70]. 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 [37], [44] and computational photography [84].
- **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 [96]. 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.

2.3. Highlights of the Year

The first highlight of the year was the team's strong participation at SIGGRAPH: three full technical papers, one talk, and the organization of Inria booth at the exhibition. As a result, the projects got major media coverage (100 000 views of paper videos, publications in internet media) and strong industrial interest (Zeiss, Schneider-Kreuznach, Blender, The Foundry, 3DS).

As a second highlight, the *Eigen* library – whose main contributors include Gaël Guennebaud and Desiré Nuentsa – has received the "High Quality Software in Geometry Processing Award 2013" at the Symposium on Geometry Processing (SGP), a prestigious prize for software development. This prize shows that the library has become a quasi-standard in the field.

The third hightlight is shared with our partners of the ANR SeARCH project (see Section 7.2.1). The results of our collaborative work on the Isis statue was one of the key events of a 6 months exhibition at the "Musée Royal de Mariemont" in Brussels. We also had a major success with our interactive installation "The Revealing Flashlight" (cf. Figure 3). These results were made possible by the new visualization and re-assembly tools developed in our team.

Figure 3. The installation "The Revealing Flashlight" lets visitors explore ancient artifacts interactively.

3. Research Program

3.1. Related Scientific Domains

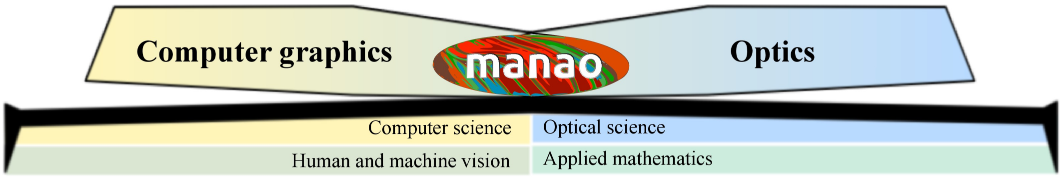


Figure 4. Related scientific domains of the MANAO project.

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 4) 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 [49] 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 [61], [62] and display [60] 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 7.3). 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 [51] or differential analysis [83], 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) 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 [7], 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.

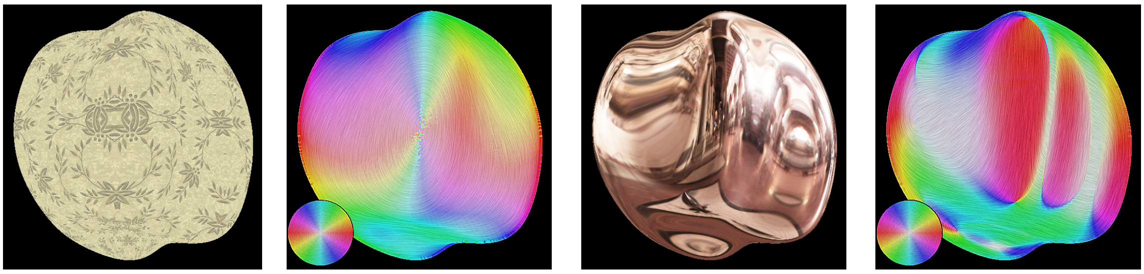
Results: Theoretical tools and numerical models for analyzing and simulating the observed optical phenomena.

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 [57] in order to develop tailored strategies [100]. For instance, starting from simple direct lighting, more complex phenomena have been progressively introduced: first diffuse indirect illumination [55], [91], then more generic inter-reflections [64], [49] and volumetric scattering [88], [46]. 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 [45]. 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 [90] but are difficult to extend to non-piecewise-constant data [93]. More recently, researches prefer the use of Spherical Radial Basis Functions [97] or Spherical Harmonics [82]. For more complex data, such as reflective properties (e.g., BRDF [76], [65] - 4D), ray-space (e.g., Light-Field [73] - 4D), spatially varying reflective properties (6D - [86]), new models, and representations are still investigated such as rational functions [79] or dedicated models [33] and parameterizations [89], [94]. 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 [79].

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



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

Figure 5. First-oder analysis [102] 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.

(e.g., differential [83] and frequency analysis [51]). Such an approach has leaded us to exhibit the influence of surfaces flows (depth and normal gradients) into lighting pattern deformation (see Figure 5). For a **human observer**, this correspond to one recent trend in computer graphics that takes into account the human visual systems [52] 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.

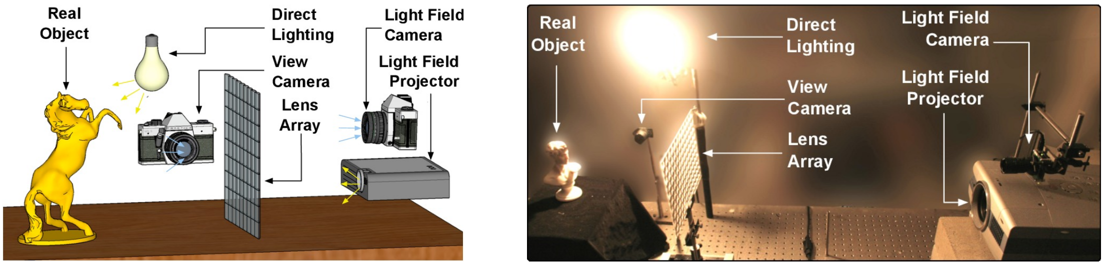


Figure 6. Light-Field transfer: global illumination between real and synthetic objects [44]

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 [73], [60]. We consider projecting systems and surfaces [41], for personal use, virtual reality and augmented reality [37]. 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 [54], [53]. These resulting systems have to acquire the different phenomena described in Axis 1 and to display them, in an efficient manner [58], [34], [59], [62]. 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 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 [63].

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 [62], [81]). Similarly, increasing the number of viewpoints is a way toward the creation of full 3D displays [73]. 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., [80], [104]).

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. [44]. 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 [69] are one of the key technologies to develop such acquisition (e.g., Light-Field camera [1] [63] and acquisition of light-sources [54]), projection systems (e.g., auto-stereoscopic displays). Such an approach is versatile and may be applied to improve classical optical instruments [68]. More generally, by designing unified optical and digital systems [77], 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 [79]. Second, we have to integrate signals from multiple sensors (such as GPS, accelerometer, ...) to prevent some computation (e.g., [70]). Finally, the experience of the group in surface modeling help the design of optical surfaces [66] 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

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.

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

(a) Global illumination [78] (b) Shadows [35] (c) Shape enhancement [9] (d) Shape depiction [32]

Figure 7. 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.

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 7c,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 [10], [67] or stylized shading [39],[9] 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 7a,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 [103], motion blur [51], depth of field [92], 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 [4], [50]. 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 [43]. Independent image processing for each viewpoint may disturb the feeling of depth by introducing inconsistent information in each images. Finally, more dedicated displays [60] 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 [6], [1]. 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., [98]): 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 8), 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 [98]), 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.

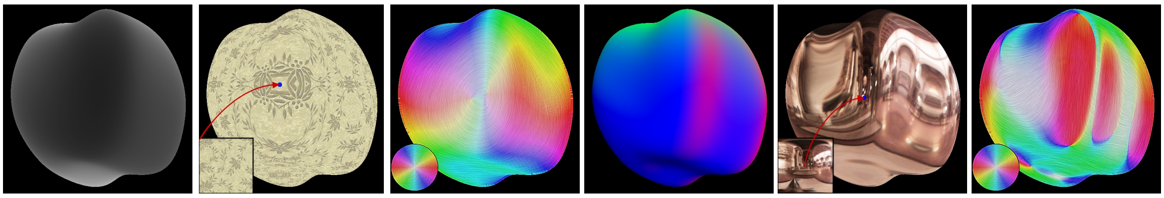

(a) (b) (c) (d) (e) (f)

Figure 8. Based on our analysis [102] (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. Software and Platforms

4.1. EIGEN

Participants: G. Guennebaud, D. Nuentsa

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. This year, Eigen received the **"high-quality software in geometry processing award"** from the Symposium on Geometry Processing 2013 which was held in Genova, Pisa.
Facts:

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

4.2. PatateLib

Participants: N. Mellado, G. Ciaudo, 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, organised in modules that each tackle 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 developped 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 developped in 2014.
Facts:

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

4.3. 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 offer also a good integration with high-level mathematical programming languages, such as MATLAB or GNU Octave. `pfstools` can be used as the extension of MATLAB or Octave for reading and writing HDR images or simply to store effectively large matrices. The `pfstools` package is an attempt to integrate the 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 an algorithm for the photometric calibration of cameras and for the recovery of high dynamic range (HDR) images from the set of low dynamic range (LDR) exposures. Maintenance of the pfscalibration package is done 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 of 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

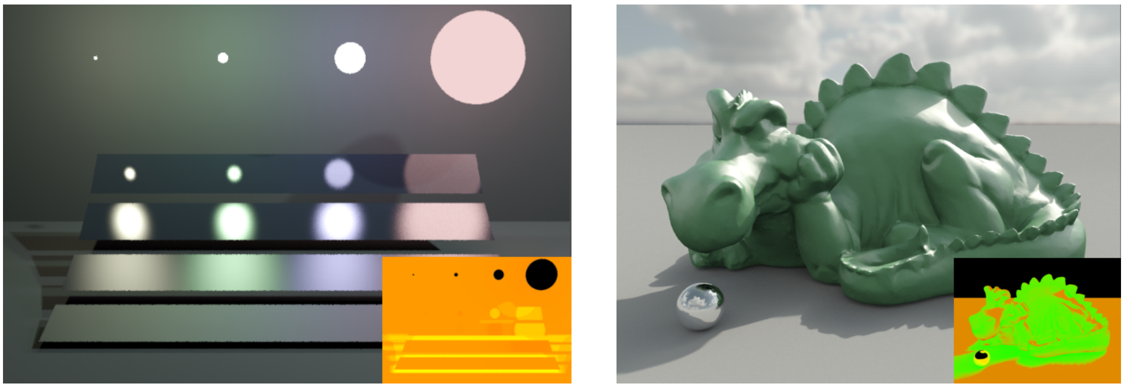
5. New Results

5.1. Axis 1:Analysis and Simulation

5.1.1. Second Order Analysis of Variance in Multiple Importance Sampling

Participants: H. Lu, R. Pacanowski, X. Granier

Monte Carlo Techniques are widely used in Computer Graphics to generate realistic images. Multiple Importance Sampling reduces the impact of choosing a dedicated strategy by balancing the number of samples between different strategies. However, an automatic choice of the optimal balancing remains a difficult problem. Without any scene characteristics knowledge, the default choice is to select the same number of samples from different strategies and to use them with heuristic techniques (e.g., balance, power or maximum). We introduced [16] a second-order approximation of variance for balance heuristic. Based on this approximation, we automatically distribute samples for direct lighting without any prior knowledge of the scene characteristics. For all our test scenes (with different types of materials, light sources and visibility complexity), our method actually reduces variance in average (see Figure 9). This approach will help developing new balancing strategies.



Low to high glossy materials with five diffuse area light sources Glossy materials with high-frequency environment map lighting

*Figure 9. Our per-pixel second-order approximation of the variance leads to a new and automatic approach for balancing the number of samples between two different sampling strategies. Except for light sources, the inset images show the sample distribution for each pixel. The yellow corresponds to the default balance heuristic strategy [101]. Compared to the balance heuristic, the variance is reduced by (**Left**) 26% and (**Right**) 20% in average (14% and 11% for the standard deviation).*

5.1.2. Rational BRDF

Participants: R. Pacanowski, L. Belcour, X. Granier

Over the last two decades, much effort has been devoted to accurately measuring Bidirectional Reflectance Distribution Functions (BRDFs) of real-world materials and to use efficiently the resulting data for rendering. Because of their large size, it is difficult to use directly measured BRDFs for real-time applications, and fitting the most sophisticated analytical BRDF models is still a complex task.

We have presented Rational BRDF [21], a general-purpose and efficient representation for arbitrary BRDFs, based on Rational Functions (RFs). Using an adapted parametrization, Rational BRDFs offer 1) a more compact and efficient representation using low-degree RFs, 2) an accurate fitting of measured materials with guaranteed control of the residual error, and 3) efficient importance sampling by applying the same fitting process to determine the inverse of the Cumulative Distribution Function (CDF) generated from the BRDF for use in Monte-Carlo rendering.

5.1.3. Decomposing intensity gradients into information about shape and material

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

Recent work has shown that the perception of 3D shapes, material properties and illumination are interdependent, although for practical reasons, each set of experiments has probed these three causal factors independently. Most of these studies share a common observation though: that variations in image intensity (both their magnitude and direction) play a central role in estimating the physical properties of objects and illumination. Our aim is to separate retinal image intensity gradients into contributions of different shape and material properties, through a theoretical analysis of image formation [11].

We find that gradients can be understood as the sum of three terms: variations of surface depth conveyed through surface-varying reflectance and near-field illumination effects (shadows and inter-reflections); variations of surface orientation conveyed through reflections and far-field lighting effects; and variations of surface micro-structures conveyed through anisotropic reflections. We believe our image gradient decomposition constitutes a solid and novel basis for perceptual inquiry. We first illustrate each of these terms with synthetic 3D scenes rendered with global illumination. We then show that it is possible to mimic the visual appearance of shading and reflections directly in the image, by distorting patterns in 2D. Finally, we discuss the consistency of our mathematical relations with observations drawn by recent perceptual experiments, including the perception of shape from specular reflections and texture. In particular, we show that the analysis can correctly predict certain specific illusions of both shape and material.

5.2. Axis 2: From Acquisition to Display

5.2.1. Interactive Spatial Augmented Reality

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

We propose the revealing flashlight [26], a new interaction and visualization technique in spatial augmented reality that helps to reveal the details of cultural heritage artifacts (see Figure 3), since they often contain details that are difficult to distinguish due to aging effects such as erosion. We locally and interactively augment a physical artifact by projecting an expressive 3D visualization that highlights its features, based on an analysis of its previously acquired geometry at multiple scales.

Our novel interaction technique simulates and improves the behavior of a flashlight: according to 6-degree-of-freedom input, we adjust the numerous parameters involved in the expressive visualization - in addition to specifying the location to be augmented. This makes advanced 3D analysis accessible to the greater public with an everyday gesture, by naturally combining the inspection of the real object and the virtual object in a co-located interaction and visualization space. The revealing flashlight can be used by archeologists, for example, to help decipher inscriptions in eroded stones, or by museums to let visitors interactively discover the geometric details and meta-information of cultural artifacts. We confirm its effectiveness, ease-of-use and ease-of-learning in an initial preliminary user study and by the feedbacks of two public exhibitions.

5.2.2. *High Dynamic Range, Multispectral, Polarization, and Light-Field Imaging*

Participants: A. Manakov, J. Restrepo, R. Hegedüs, I. Ihrke

In [5] we propose a non-permanent add-on that enables plenoptic imaging with standard cameras (see also Figure 10 top and left). Our design is based on a physical copying mechanism that multiplies a sensor image into a number of identical copies that still carry the plenoptic information of interest. Via different optical filters, we can then recover the desired information. A minor modification of the design also allows for aperture sub-sampling and, hence, light-field imaging. As the filters in our design are exchangeable, a reconfiguration for different imaging purposes is possible. We show in a prototype setup that high dynamic range, multispectral, polarization, and light-field imaging can be achieved with our design.

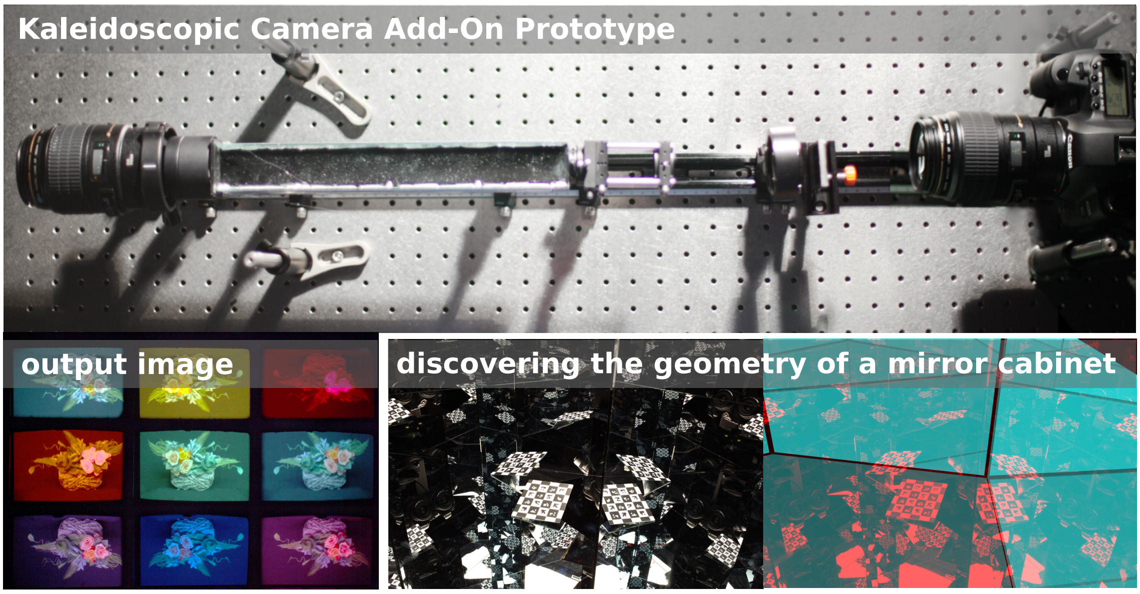


Figure 10. (Top) Novel optical converter module that can be placed between a camera and its lens. This module can be configured flexibly to allow for multi-spectral, polarization, high-dynamic range, or light field imaging. It works by splitting the original image into a number of copies that can be optical filtered separately (Bottom, Left). Computational post-processing allows for unprecedented flexibility in image post-processing such as post-capture control of illumination, polarization state, exposure setting or focus. (Bottom,Right) The basis of the operational principle of the aforementioned prototype is imaging in mirror systems.

5.2.3. *Structure of a Planar Mirror System from Multiple Observations of a Single Point*

Participants: I. Reshetouski, A. Manakov, I. Ihrke

We have investigated the problem of identifying the position of a viewer inside a room of planar mirrors with unknown geometry in conjunction with the room's shape parameters [25] (see also Figure 10 bottom right). We consider the observations to consist of angularly resolved depth measurements of a single scene point that is being observed via many multi-bounce interactions with the specular room geometry. Applications of this problem statement include areas such as calibration, acoustic echo cancelation and time-of-flight imaging. We theoretically analyze the problem and derive sufficient conditions for a combination of convex room geometry, observer, and scene point to be reconstructable. The resulting constructive algorithm is exponential in nature and, therefore, not directly applicable to practical scenarios.

To counter the situation, we propose theoretically devised geometric constraints that enable an efficient pruning of the solution space and develop a heuristic randomized search algorithm that uses these constraints to obtain an effective solution. We demonstrate the effectiveness of our algorithm on extensive simulations as well as in a challenging real-world calibration scenario.

5.2.4. *Mirrors in Computer Graphics, Computer Vision and Time-of-Flight Imaging*

Participants: I. Reshetouski, I. Ihrke

We have investigated the state of the art in dealing with the geometry of mirror systems [28].

Mirroring is one of the fundamental light/surface interactions occurring in the real world. Surfaces often cause specular reflection, making it necessary to design robust geometry recovery algorithms for many practical situations. In these applications the specular nature of the surface is a challenge. On the other side, mirrors, with their unique reflective properties, can be used to improve our sensing modalities, enabling applications such as surround, stereo and light field imaging. In these scenarios the specular interactions are highly desirable. Both of these aspects, the utilization and circumvention of mirrors are present in a significant amount of publications in different scientific areas. These publications are covering a large number of different problem statements as well as many different approaches to solutions. In this survey we focused on a collection and classification of the work in this area.

5.2.5. *Computational Fabrication and Display of Material Appearance*

Participant: I. Ihrke

We have investigated the state of the art in digital material fabrication and active display technology [22].

After decades of research on digital representations of material and object appearance, computer graphics has more recently turned to the problem of creating physical artifacts with controllable appearance characteristics.

While this work has mostly progressed in two parallel streams – display technologies as well as novel fabrication processes – we believe there is a large overlap and the potential for synergies between these two approaches. In this report, we summarize research efforts from the worlds of fabrication display, and categorize the different approaches into a common taxonomy. We believe that this report can serve as a basis for systematic exploration of the design space in future research.

5.3. Axis 3: Rendering, Visualization and Illustration

5.3.1. *Real-Time Sampling from Captured Environment Map*

Participants: H. Lu, R. Pacanowski, X. Granier

We have introduced [23] a simple and effective technique for light-based importance sampling of dynamic environment maps based on the formalism of Multiple Importance Sampling (MIS). The core idea is to balance per pixel the number of samples selected on each cube map face according to a quick and conservative evaluation of the lighting contribution: this increases the number of effective samples. In order to be suitable for dynamically generated or captured HDR environment maps, everything is computed on-line for each frame without any global preprocessing. Our MIS formalism can be easily extended to other strategies such as BRDF importance sampling.

5.3.2. *Screen-Space Curvature for Production-Quality Rendering and Compositing*

Participants: N. Mellado, P. Barla, G. Guennebaud, P. Reuter

Curvature is commonly employed for enhancing details in textured 3D models, or to modulate shading at the rendering or compositing stage. However, existing methods that compute curvature in object space rely on mesh-based surfaces and work at the vertex level. Consequently, they are not well adapted to production-quality models that rely on either subdivision surfaces with displacement and bump maps, or on implicit and procedural representations. In practice they would require a view-dependent scene discretization at each frame, to adapt geometry to visible details and avoid aliasing artifacts. Our approach [24] is independent of both scene complexity and the choice of surface representations since it computes mean curvature from scratch at each frame in screen-space. It works without any pre-process and provides a controllable screen-space scale parameter, which makes it ideal for production requirements, either during rendering or compositing.

Figure 11. Time-varying light samples distribution for one pixel (cyan dot) on the dragon model when lit with a dynamic environment map [95]. This example runs in average at 145 fps using Multiple Importance Sampling with 50 samples for the Lafortune energy conserving Phong BRDF with a shininess exponent set to 150.

5.3.3. Smooth Surface Contours with Accurate Topology

Participant: P. Bénard

Computing the visible contours of a smooth 3D surface is a surprisingly difficult problem, and previous methods are prone to topological errors, such as gaps in the outline. Our approach [13] 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. We demonstrate results computing contours of complex 3D objects, on which our method eliminates the contour artifacts of other methods.

5.4. Axis 4: Editing and Modeling

5.4.1. Implicit Skinning and Modeling

Participant: G. Guennebaud

Geometric skinning techniques, such as smooth blending or dual-quaternions, are very popular in the industry for their high performances, but fail to mimic realistic deformations. Other methods make use of physical simulation or control volume to better capture the skin behavior, yet they cannot deliver real-time feedback. In collaboration with IRIT (Toulouse) and the Imagine team (Grenoble), we developed the first purely geometric method handling skin contact effects and muscular bulges in real-time. Our insight is to exploit the advanced composition mechanism of volumetric, implicit representations for correcting the results of geometric skinning techniques (cf. Figure 12-a). The mesh is first approximated by a set of implicit surfaces. At each animation step, these surfaces are combined in real-time and used to adjust the position of mesh vertices, starting from their smooth skinning position. This deformation step is done without any loss of detail and seamlessly handles contacts between skin parts. As it acts as a post-process, our method fits well into the standard animation pipeline. Moreover, it requires no intensive computation step such as collision detection, and therefore provides real-time performances. This work has been published at Siggraph this year [20] and featured by the 3DVF website http://www.3dvf.com/actualite-6678-siggraph-2013-methode-skinning-implicite.html.

Still in collaboration with IRIT, we addressed the challenging problem of finding adequate bounds for implicit modeling with compact field functions. Recent advances in implicit surface modeling now provide highly controllable blending effects. These effects rely on the field functions of $\mathbb{R}^3 \to \mathbb{R}$ in which the implicit surfaces are defined. In these fields, there is an outside part in which blending is defined and an inside part. The implicit surface is the interface between these two parts. As recent operators often focus on blending, most efforts have been made on the outer part of field functions and little attention has been paid on the inner part. Yet, the inner fields are important as soon as difference and intersection operators are used. This makes its quality as crucial as the quality of the outside.

In this work we analyzed these shortcomings, and deduced new constraints on field functions such that differences and intersections can be seamlessly applied without introducing discontinuities or field distortions. In particular, we showed how to adapt state of the art gradient-based union and blending operators to our new constraints. Our approach enables a precise control of the shape of both the inner or outer field boundaries. We also developed a new set of asymmetric operators tailored for the modeling of fine details while preserving the integrity of the resulting fields. This work has been published at Shape Modeling International 2013 [14].


(a) (b)

Figure 12. (a) Illustration of the implicit skinning technique. (b) Surface reconstruction from non-oriented normals

5.4.2. Surface reconstruction

Participants: J. Chen, G. Guennebaud, P. Barla, X. Granier

Reconstructing a smooth surface from a set of points is still a challenging problem. Most of the popular techniques assume correctly oriented points as inputs. However, in many situations, computing a consistent orientation of the normal field is as difficult as the reconstruction itself. In a recent work, we extended the Algebraic Point Set Surface method to support non oriented normals (cf. Figure 12-b). By fitting algebraic spheres, our approach outperforms simple local methods based on non-oriented planar fit while still being fast since it involves only local computations. The core of this new technique also proved to be useful for image processing. This work as been published at Computer Graphics Forum [3].

5.4.3. Manipulation of Anisotropic Highlights

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

We have developed [19] 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. CIFRE PhD contract with Technicolor

Participants: C. Buron, G. Guennebaud and X. Granier

For this project, we aim to provide interactive generation and rendering for very large sceneries, based on grammars. We aim also to offer artist-friendly methods for controlling grammar behavior.

7. Partnerships and Cooperations

7.1. Regional Initiatives

7.1.1. CTP materials (2011-2015):

U. Zaragoza, U. Girona

Leader: P. Barla (*MANAO*)

This collaboration between regions on both French and Spanish sides of Pyrénées aims at studying material properties through their connections between physical and image space. Although the purpose of such a study is general in scope, we also target a particular application: the acquisition of material properties from a single image of an object of unknown shape, under unknown illumination.

7.2. National Initiatives

7.2.1. ANR

7.2.1.1. 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 offline, high-quality simulation or interactive simulations.

7.2.1.2. "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.

7.2.1.3. SeARCH (2009-2013):

PFT3D Archéovision (CNRS), CEAlex (USR CNRS 3134), ESTIA

Leader: P. Reuter

Cultural Heritage (CH) artifacts often come as a set of broken fragments leading to difficult 3D puzzles and sometime impossible to solve in a real world. The project's goal is to propose solutions from on-site acquisition, 3D surface reconstruction and semi-automatic virtual reassembly, taking into account the expertise of CH scientists. This project ended officially in March 2013, and we organized a closing conference and meeting in Bordeaux. We presented the results at "ANR - Les rencontres du numérique de l'ANR" in Paris at April 17th and 18th, 2013.

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 Projects

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

partners available at http://www.v-must.net/participants
Leader: S. Pescarin (CNR - Italy)
V-MusT.net is a new 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):

Giessen University, Université Paris-Descartes, Bilkent University, Université de Leuven, Delft University, Birmingham University, Philips and NextLimit
Leader: Roland 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. Deutsche Forschungsgemeinschaft

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

Inria
Leader: Ivo Ihrke (Inria)
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.

8. Dissemination

8.1. Scientific Animation

8.1.1. Conference organization

PRISM2 workshop: second workshop of the PRISM network (6 invited speakers, 42 attendees, 3 days).

IHM 2013 workshop: 25th francophone conference on human-computer interaction (125 attendees, 3 days).

INM 2013 workshop: Imaging New Modalities (in conjunction with German Conference on Pattern Recognition GCPR: 200 attendees, 3 days - workshop 1 day).

8.1.2. Program committee

Conferences: International Conference on Computer Vision (ICCV) 2013, Computer Vision and Pattern Recognition (CVPR) 2013, Eurographics (EG) 2014, Siggraph Asia Posters & Technical Briefs 2013, Interneational Conference on Computational Photography (ICCP) 2013, British Machine Vision Conference (BMVC) 2013, International Conference on 3D Vision (3DV) 2013, High Performance Graphics (HPG) 2013, Workshop on Computational Cameras and Displays (CCD), Pacific Graphics (PG) 2013, Eurographics Symposium on Rendering (EGSR) 2013, Web3D 2013, International Conference in Central Europe on Computer Graphics, Visualization, and Computer Vision (WSCG) 2013

8.1.3. Reviews

The members of *MANAO* have also participated to the reviewing process for conferences and journals:

Journals: ACM Transaction on Graphics (TOG), Computer Graphics Forum (CGF), International Journal of Computer Vision (IJCV), Transactions on Pattern Recognition and Machine Intelligence (PAMI), Applied Optics (AO), Computer and Graphics (C&G), The Visual Computer (VC), Signal Image and Video Processing, ACM Journal of Computing and Cultural Heritage, Image & Vision Computing

Conferences: ACM Siggraph 2013, ACM Siggraph Asia 2013, Eurographics 2014, Eurographics Symposium on Rendering 2013, Graphics interface (GI) 2013, CGI 2013, Web3D 2013.

Grant Proposals: NSERC (Canada)

8.1.4. Committees

In 2013, the members of *MANAO* have been involved in the following responsibilities:

Inria - Evaluation committee member - Gaël Guennebaud.

Inria Bordeaux - commission for technological development (CDT) - Gaël Guennebaud.

AFIG 2013 - Best paper jury - Gaël Guennebaud.

IHM 2013 - Demo chair - Patrick Reuter.

8.1.5. Invited Talks

Talk "The archeologist of the future" at TedX Basque Country, June, Bidart, France.

Keynote Talk “Computational Optical Measurement and Display” at Journée Imagerie Optique Non-Conventionelle, Paris

Invited Talk “Computational Optical Measurement and Display” at SPIE student chapter University of Rochester

Invited Talk “A Reconfigerable Camera Add-On for HDR, Multi-Spectral, Polarization, and Light-Field Imaging” at University of British Columbia

Invited Talk “Computational Optical Measurement and Display” at Schloss Dagstuhl, Germany

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

The members of our team are involved in teaching computer science at University Bordeaux I and II, 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 I, France.

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

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

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

Master : Xavier Granier and Romain Pacanowski, Radiometry and Colorimetry, 15 HETD, M1, IOGS, France

Master : Gaël Guennebaud and Simon Boyé, High-performance 3D Graphics, 60 HETD, M1, Univ. Bdx I, France.

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

Master : Ivo Ihrke, Computational Optical Imaging, 20 HETD, M1, IOGS, France

Master : Christophe Schlick, Martin Hachet, Pierre Bénard and Jeremy Laviole, Image Synthesis and Virtual Reality, 60 HETD, M2, ENSEIRB, France

Licence : Patrick Reuter, Digital Imaging, 36 HETD, L3, Univ. Bdx 2, 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 II, 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, Jean-Eudes Marie & Gaël Guennebaud & Xavier Granier

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

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

PhD : Boris Raymond, Rendering and manipulation of anisotropic materials , Univ. Bordeaux, Pascal Barla & Gaël Guennebaud & Xavier Granier

PhD : Ilya Reshetouski, Mirror Systems for Extended View Point Coverage, Saarland University, Ivo Ihrke

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

PhD : Brett Ridel, Interactive spatial augmented reality, Univ. Bordeaux, Patrick Reuter & Xavier Granier

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

8.2.3. Juries

PhD : Jean-Patrick Roccia [87], 24th of May, Toulouse, France.

PhD : Adrien Bernhardt [36], 3th of July, Grenoble, France.

PhD : Suman-Kumar Maji [71], 12th of November, Bordeaux, France.

PhD : Violaine Todoroff, 9th of December, Toulouse, France.

8.3. Popularization

8.3.1. Exhibitions

Organization of the Inria's booth at Siggraph 2013, Anaheim, US.

Participation at the temporary exhibition "Eternal Egypt" at the Museum “Allard Pierson” in Amsterdam, The Netherlands, with the interactive spatial augmented reality setup “The Revealing Flashlight” [26].

Participation at the temporary exhibition “Du Nil à Alexandrie. Histoires d'eaux” at the Museum “Mariemont” near Bruxelles, Belgium with the 1/5 scale reproduced reassembled Isis statue within the ANR SeARCH project.

8.3.2. Tutorials and Workshops

Tutorial on the Eigen library at Cg-libs, Italian Eurographics chapter, June, Pisa, Italy.

Tutorial at Eurographics 2013, Girona, Spain

Tutorial at German Conference on Pattern Recognition 2013, Saarbrücken, Germany

Workshop at the Nodem 2013 conference: "Interactive exhibitions with 3D content: Virtual Museums - Workshop", December, Stockholm, Sweden.

8.3.3. Miscellaneous

Organization of Miniforum 3D - a meeting between students, researchers, and local industry

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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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Publications of the year

Articles in International Peer-Reviewed Journals

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