



UNIVERSITÉ DE  
RENNES 1



Project-Team FRVSense

## ***Fast Rendering and Visualization Sense***

*Rennes*

| *Activity Report*

2016



## 1 Team

### **Head of the team**

Kadi Bouatouch, Professor, University of Rennes 1

### **Administrative assistant**

Maryse Fouché, INRIA

### **University of Rennes 1 personnel**

Rémi Cozot, Assistant Professor

### **External collaborators**

Christian Bouville, External Collaborator

### **PhD students**

Matis Hudon, *CIFRE* grant since November 2013

Hristina Hristova, *MENRT* grant since October 2014

Cambodge Bits *B-COM* grant since October 2014

Maxime Rousselot, *CIFRE* grant since October 2016

## 2 Overall Objectives

### 2.1 Objectives

The different topics that will be addressed by the team are:

1. Real-time rendering and global illumination algorithms exploiting the performances of the new GPUs (Graphics Processing Units);
2. Color and visual perception;
  - Color appearance models
  - Color transfer
  - HDR (High Dynamic Range) imaging and tone mapping
3. Inverse lighting and image aesthetics

Our objectives for the these topics are:

- Real-time rendering and global illumination

The main objective is real-time global illumination computation. This is a real challenge that want to take up all the researchers involved in 3D movie and game video as well as virtual reality applications. We want to make available to artists a tool for photorealistic real-time rendering.

The global illumination problem (called GI from now on) has been intensively studied over the last decades. Many approaches (path tracing, bidirectional path tracing, photon mapping, etc.) have been proposed to solve it. As the GI problem is mathematically expressed with an integral equation, most of these methods use a Monte Carlo algorithm with an importance sampling defined on the integral domain. However, in certain cases, the importance sampling strategy does not guaranty satisfying results in a reasonable computation time. Indeed, this sampling strategy is efficient if the probability density function (pdf) used to generate samples is proportional to the integrand. In the GI context, this pdf is not known and it is challenging to define an efficient function which takes into account all the problems to be solved. As a solution Veach<sup>[Vea97]</sup> proposed to use the Metropolis-Hastings light transport (MLT) algorithm which has the ability to build an arbitrary probability density by random walking. This random walk is managed by an importance function which gives the relative importance between different states of a Markov Chain. However, in GI, this importance function is often designed in the image space and precomputed. We proposed a MLT-based GI method that uniformly distributes the resulting estimation error over all the computed image. Our method does not rely on a fixed scalar function but updates it after each pass which consists in generating an amount of photons from the light sources. The new importance function is evaluated in the 3D space rather than in 2D.

For global illumination we have also proposed another integration procedure known as Bayesian Monte Carlo integration (BMC)<sup>[O'H87]</sup>. As opposed to importance sampling methods, BMC does not require the samples to be drawn from a predefined pdf and does not take into account samples location. The price to pay for this is a higher computational cost per samples but in a recent paper<sup>[?]</sup>, we have shown that this cost can be kept to the same level as for importance sampling with a suboptimal solution. Compared to the usual combination of importance and stratified sampling procedures, our proposed BMC method allows a 23% decrease in the number of samples for the same noise level. However, these results have only been obtained for the computation of the diffuse component in the final gathering step of a photon mapping renderer and cannot be easily extended to the implementation of a full global illumination renderer. Our approach will allow to analyze for which rendering step or for which effect the use of BMC could be beneficial and then experiment solutions. A first objective will be to deal with the rendering of the glossy component. An important aspect of this work will be the integration of prior knowledge. We think that BMC can provide a very powerful framework for very efficient rendering methods.

[Vea97] E. VEAH, *Robust Monte Carlo methods for light transport simulation*, PdD Thesis, Stanford University, 1997.

[O'H87] A. O'HAGAN, "Monte-Carlo is fundamentally unsound", *The Statistician* 36, 2/3, 1987, p. 247–249.

We are also working on QMC (Quasi Monte Carlo) applied to GI. We have proposed several metrics to evaluate the performance of sampling the hemisphere.

- Color and visual perception
  - Color appearance models and tone mapping
 

Our main objective is to propose approaches allowing to combine global illumination engines and visual perception based algorithms in order to compute perceptually realistic images. We have already proposed a robust and real-time model of visual attention which mixes top-down and bottom-up approaches in the context virtual reality<sup>[HBO<sup>+</sup>10,HLC<sup>+</sup>10]</sup>. We have also proposed and evaluated methods to enhance visual feedback by adding a depth of field blur in VR applications<sup>[HLCC08]</sup>. In the short-term, our work focuses onto three topics:

    - \* the creation of a robust and real-time chromatic adaptation algorithm (estimate of white balance) in the context of global illumination;
    - \* the enhancement of tone mapping algorithm using our visual attention model;
    - \* the proposal of new tone mapping techniques for dynamic scenes;
    - \* the creation of HDR images from two LDR images (flash and non flash);
    - \* new transformations of distributions for transferring color, gradient and different styles.

Once we will be able to evaluate the perceptual realism of the rendered images, then in the long-term, one challenge will be to inverse the perceptual models and let the artist/designer specify some constraints on image appearance and perception. The rendering parameters will be tuned to satisfy these constraints. Note that a high level model of constraints can be used by an artist to enhance the visual perception of 3D scenes.

### 3 Scientific Foundations

#### 3.1 Global Illumination

**Keywords:** Global illumination, relighting, bayesian Monte Carlo, multi-view rendering, image-based rendering, color appearance model, high dynamic range.

To achieve realistic rendering, one has to compute global illumination accounting for: multiple reflections and refractions, sub-surface scattering (within skin, marble), multiple scattering

- 
- [HBO<sup>+</sup>10] S. HILLAIRE, G. BRETON, N. OUARTI, R. COZOT, A. LECUYER, “Using a Visual Attention Model to Improve Gaze Tracking Systems in Interactive 3D Applications”, *Computer Graphics Forum*, 2010.
- [HLC<sup>+</sup>10] S. HILLAIRE, A. LECUYER, R. CORTE, T., R. COZOT, G. BRETON, “A Real-Time Visual Attention Model for Predicting Gaze Point During First-Person Exploration of Virtual Environments”, in : *VRST 2010*, 2010.
- [HLCC08] S. HILLAIRE, A. LECUYER, R. COZOT, G. CASIEZ, “Depth-of-Field Blur Effects for First-Person Navigation in Virtual Environments”, *Computer Graphics and Applications*, 2008.

in participating media (smoke, fire, dust, clouds), chromatic adaptation, tone mapping, etc. It is well known that global illumination computation is demanding in terms of computing and memory resources. This is why the team members have already proposed new solutions based on irradiance/radiance caching methods implemented on the GPU to speed up the different computations involved in global illumination and rendering algorithms[2, ?].

Radiance caching has also been used to simulate multiple scattering within participating media[?]. Indeed, we proposed a technique for efficiently rendering participating media with irradiance caching scheme using Monte Carlo ray tracing. Our approach extends the original algorithm for surfaces to volumes rendering. Our method allows us to adjust density of cached records according to illumination changes and to store both direct and indirect contributions in the records but also multiple scattering due to medium. To achieve this, we proposed an adaptive shape for records depending on geometrical features and irradiance variations. In order to avoid a too high density of cached records where it is not necessary (for example away from the observer inside a medium with high absorption and scattering properties) a new method is proposed to control the density of the cache during the addition of new records. This volume density control is depending of the interpolation quality with the existing records and the photometric characteristics of the participating media. Limiting the number of records in the volume can accelerate both the computation pass (computation of irradiance and gradients may be time-consuming for a record) and the final rendering pass by limiting the number of searches in the cache. Moreover, storing all contributions in records is of high importance, especially in the case of scenes having many light sources with complex geometry as well as wide surfaces exposed to daylight or again for animation rendering. Finally, instead of using an expensive ray marching to find records that cover the ray, we gather all the records along ray which contribute to the in-scattered radiance. With these different techniques, pre-computing and rendering passes are significantly speeded-up.

We have brought several contributions to global illumination: radiance cache, participating media, Metropolis Light Transport, etc. Moreover, we proposed a novel approach to progressive photon mapping for scenes containing surface and volume objects. Our method allows to handle scenes with specular and refractive objects as well as homogeneous and heterogeneous participating media.

### 3.2 Bayesian and Quasi Monte-Carlo methods for image rendering

**Keywords:** Sampling, likelihood principle, Monte Carlo.

Most global illumination rendering methods are based Monte-Carlo importance sampling but, as pointed out by OHagan in 1987<sup>[O'H87]</sup>, this procedure suffers from two inconsistencies that we will briefly present in the following. Firstly, the estimator depends on some arbitrary choice of the sampling density which violates the Likelihood principle. Secondly, this procedure ignores sample location and thus wastes important information. Although solution exists to alleviate these problems, it still remains true that choosing the right sample distribution is a difficult problem and that Monte Carlo importance sampling does not allow to easily take into account prior knowledge on the data. This leads to a waste of samples which is further

---

[O'H87] A. O'HAGAN, "Monte-Carlo is fundamentally unsound", *The Statistician* 36, 2/3, 1987, p. 247–249.

increased by the fact that samples location is not exploited. Furthermore, samples reuse from one integral computation to another is difficult since samples must be drawn from a predefined probability density function (pdf).

QMC integration is now extensively used in computer graphics (see e.g. [SEB08]). Keller has shown in [Kel13] that QMC techniques can be applied in a consistent way to deal with a wide range of problems (anti-aliasing, depth of field, motion blur, spectral rendering, etc.). However, few applications have been reported in the literature specifically addressing hemispherical sampling with a view of computing the illumination integral. Unlike the unit square sampling case, no explicit construction of optimal point sets for spherical sampling is known and generally the spherical point sets are generated by lifting point sets from the unit square to the unit sphere through an equal-area transform. Although such point constructions are not proved to be optimal, recent results from the numerical analysis literature suggest that both (0, 2)-sequences and Fibonacci lattices lifted to the sphere are quite close to optimality in terms of discrepancy [ABD12].

Nevertheless their performance is not exactly equivalent: several authors have shown that spherical Fibonacci (SF) lattices are particularly well-suited to sphere sampling compared to other low-discrepancy point sets. Furthermore, similar point structures arise spontaneously in nature so as to implement a best packing strategy on the sphere (e.g. packing of seeds in the sunflowers head [Vog79]), a clear indication that these structures have intrinsically good spherical uniformity properties. We introduced theoretical aspects on QMC spherical integration that have never been used in the graphics community [5]. In concrete terms, we define worst case integration error (w.c.e.), spherical cap discrepancy (s.c.d.) and an inter-samples distance-based energy metrics, which allows to assess the quality of a spherical samples set for spherical integration.

### 3.3 Color, Visual Perception and Inverse Lighting

**Keywords:** Color appearance model, visual perception, tone mapping, white balancing, high dynamic range.

**Color appearance models and visual perception** Global illumination algorithms provide, as results, physically based values that need to be transformed into displayable RGB

- 
- [SEB08] P. SHIRLEY, D. EDWARDS, S. BOULOS, “Monte Carlo and Quasi-Monte Carlo Methods for Computer Graphics”, in : *Monte Carlo and Quasi-Monte Carlo Methods 2006*, A. Keller, S. Heinrich, and H. Niederreiter (editors), Springer Berlin Heidelberg, 2008, p. 167–177, [http://dx.doi.org/10.1007/978-3-540-74496-2\\_8](http://dx.doi.org/10.1007/978-3-540-74496-2_8).
  - [Kel13] A. KELLER, “Quasi-Monte Carlo Image Synthesis in a Nutshell”, in : *Monte Carlo and Quasi-Monte Carlo Methods 2012*, J. Dick, F. Y. Kuo, G. W. Peters, and I. H. Sloan (editors), *Springer Proceedings in Mathematics and Statistics*, 65, Springer Berlin Heidelberg, 2013, p. 213–249, [http://dx.doi.org/10.1007/978-3-642-41095-6\\_8](http://dx.doi.org/10.1007/978-3-642-41095-6_8).
  - [ABD12] C. AISTLEITNER, J. BRAUCHART, J. DICK, “Point Sets on the Sphere with Small Spherical Cap Discrepancy”, *Discrete and Computational Geometry* 48, 4, 2012, p. 990–1024, <http://dx.doi.org/10.1007/s00454-012-9451-3>.
  - [Vog79] H. VOGEL, “A better way to construct the sunflower head”, *Mathematical Biosciences* 44, 3-4, 1979, p. 179–189, <http://www.sciencedirect.com/science/article/pii/0025556479900804>.

images. This transformation could seem straightforward. But the human visual system does not perform a direct transformation, rather it involves some local and global adaptation operations, takes into account the viewing conditions and some cognitive tasks. To give the same visual perception as that of a user immersed in a 3D virtual world, this transformation into images of these physical values must take into account the features of the human visual system (HVS) as well as the characteristics of the display device. The main key features of the human visual system to be accounted for are the luminance adaptation, the chromatic adaptation, the focus point (at which the user is looking) and the depth of field. On the display device side, we have to take into account the luminance range, the color range, the size of the screen and if necessary the stereo features.

Chromatic adaptation consists in recovering the color appearance of objects as if the user was within a 3D scene (as if he sees directly the scene). But color appearance for the human visual system does not depend only on the spectral radiance of the stimulus, but it also takes into account the viewing conditions. Color appearance models allow to model the perception of color stimulus according to the viewing conditions through colorimetric and photometric quantities such as: brightness, lightness, chroma, saturation, colorfulness, and hue of the stimulus [KJF07,Fai05]. Many works also deal with chromatic adaptation. They belong to different research fields: computer graphics, color science, computer vision, etc [Fai91b,Fai91a,VK70,WW09]. Colors are perceived as constant even though the illuminant color changes. Indeed, the perceived color of a diffuse white sheet of paper is still white even though it is illuminated by a single orange tungsten light, whereas it is orange from a physical point of view. Unfortunately global illumination algorithms only focus on the physics aspects of light transport. The output of a global illumination engine is an image which has to undergo chromatic adaptation to recover the color as perceived by the HVS. We proposed a new color adaptation method [3],[?] well suited to global illumination. This method estimates the adaptation color by averaging the irradiance color arriving at the eye. Unlike other existing methods, our approach is not limited to the view frustum, as it considers the illumination from all the scene. Experiments have shown that our method outperforms the state of the art methods.

The conversion of the HDR (High Dynamic Range) luminance range of the images (computed using a global illumination algorithm) to LDR (Low Dynamic Range) images displayable onto LDR display devices is called Tone Mapping. This topic has been widely addressed by the computer graphics community. A complete state of the art of tone mapping algorithms can be found in [RWD<sup>+10</sup>]. While many solutions have been designed over the last decade,

- 
- [KJF07] J. KUANG, G. M. JOHNSON, M. D. FAIRCHILD, “iCAM06: A refined image appearance model for HDR image rendering”, *Journal of Visual Communication*, 2007.
  - [Fai05] M. D. FAIRCHILD, *Color Appearance Model, Second edition*, John Wiley and sons, Ltd, 2005.
  - [Fai91b] M. D. FAIRCHILD, “A model of incomplete chromatic adaptation”, in : *the 22nd Session of the CIE*, CIE, p. 33–34, 1991.
  - [Fai91a] M. D. FAIRCHILD, “Formulation and testing of an incomplete-chromatic-adaptation model”, *Color Research Application 16*, 1991, p. 243–250.
  - [VK70] J. VON KRIES, *Chromatic adaptation*, MIT Press, [1905] 1970, p. 109–119.
  - [WW09] A. WILKIE, A. WEIDLICH, “A Robust Illumination Estimate for Chromatic Adaptation in Rendered Images”, in : *Eurographics Symposium on Rendering 2009*, 2009.
  - [RWD<sup>+10</sup>] E. REINHARD, G. WARD, P. DEBEVEC, S. PATTANAIK, W. HEIDRICH, K. MYSZKOWSK, *High*

only few of them can cope with video sequences. Indeed, these TMOs tone map each frame of a video sequence separately, which results in temporal incoherency. Two main types of temporal incoherency are usually considered: flickering artifacts and temporal brightness incoherency. While the reduction of flickering artifacts has been well studied, less work has been performed on brightness incoherency. We proposed a method that aims at preserving spatio-temporal brightness coherency when tone mapping video sequences. Our technique computes HDR video zones which are constant throughout a sequence, based on the luminance of each pixel. Our method aims at preserving the brightness coherency between the brightest zone of the video and each other zone. This technique adapts to any TMO and results show that it preserves well spatio-temporal brightness coherency. We validate our method using a subjective evaluation. In addition, unlike local TMOs, our method, when applied to still images, is capable of ensuring spatial brightness coherency. Finally, it also preserves video fade effects commonly used in post-production.

**Inverse Lighting** As many phenomena are accounted for by global illumination algorithms, it is difficult to know beforehand what the resulting image will look like. For instance, we would like an object of a scene to be bright, with a lot of contrast, while we would like the background of the scene to be dark and uniform. Answering such specifications can be a time-consuming and tedious effort if it is not done automatically. Thus, a trial-and-error approach is not satisfactory. To obtain a satisfactory result automatically, the user has to express his aesthetic intent by providing a set of target values for properties of the final image. The goal is to change iteratively the parameters of the 3D scene to fit the specification. There are a lot of parameters to take into account. Among them are: position, size, luminance of the light sources, reflectance of the materials, distribution of the objects in the scene. The methods used to compute these lighting parameters to fit a set of constraints are called inverse lighting methods. In these methods, an objective function that accounts for the target parameters is defined to express the intent of the user. The objective function expresses the distance between the current lighting design and the desired result. To find the optimal set of parameters, an objective function has to be minimized. There are many ways to express the aesthetic intent, as there are many possible aesthetics.

We designed a new inverse lighting framework. Given a set of target parameters provided by the user, we set up a platform that can render a scene with global illumination techniques and allows to minimize the objective function to find the desired parameters (light source size, position, luminance) to meet the user's intent.

## 4 Application Domains

### 4.1 Applications

**Participants:** all participants.

The applications of our works are:

---

*Dynamic Range Imaging*, Morgan Kaufmann Publishers, San Francisco, USA, 2010.

- Lighting simulation: fast and physics-based;
- High quality video games: real-time, high realism, perception-based, help game designers to choose lighting and material properties interactively, stereoscopic and autostereoscopic;
- 3D movies: interactivity, high photorealism, perception-based, help for artists to choose lighting and material properties interactively, stereoscopic and autostereoscopic;
- Virtual and augmented reality: high realism, fast, stereoscopic and autostereoscopic.

## 5 New Results

### 5.1 Global Illumination

**Participants:** Adrien Gruson, Remi Cozot, Mickael Ribardiere, Kadi Bouatouch.

The global illumination problem (called GI from now on) has been intensively studied over the last decades. We have proposed and implemented different approaches (path tracing, bidirectional path tracing, photon mapping, etc.) to solve this problem. As the GI problem is mathematically expressed with an integral equation, most of these methods use a Monte Carlo algorithm with an importance sampling defined on the integral domain. However, in certain cases, the importance sampling strategy does not guarantee satisfying results in a reasonable computation time. Indeed, this sampling strategy is efficient if the probability density function (pdf) used to generate samples is proportional to the integrand. The pdf is not known and it is challenging to define an efficient function which takes into account all the problems to be solved. As a solution, Veach et al. [Veach 1998] proposed to use the Metropolis-Hastings light transport (MLT) algorithm which has the ability to build an arbitrary probability density by random walking. This random walk is managed by an importance function which gives the relative importance between different states of a Markov Chain. However, in GI, this importance function is often designed in the image space and precomputed. We proposed a MLT-based GI method that uniformly distributes the resulting estimation error over all the computed image. Our method does not rely on a fixed scalar function but updates it after each pass which consists in generating an amount of photons from the light sources. The new importance function is evaluated in the 3D space rather than in 2D, which drastically improves the quality of the generated images. This work has been published in the journal ACM Trans. On Graphics [4]. It will be presented at Siggraph'2017 conference.

### 5.2 Radiance Caching

**Participants:** Mahmoud Omidvar, Mickael Ribardiere, Samuel Carre, Daniel Meneveaux, Kadi Bouatouch.

Radiance caching methods have proven to be efficient for global illumination. Their goal is to compute precisely illumination values (incident radiance or irradiance) at a reasonable number of points lying on the scene surfaces. These points, called records, are stored in

a cache used for estimating illumination at other points in the scene. Unfortunately, with records lying on glossy surfaces, the irradiance value alone is not sufficient to evaluate the reflected radiance; each record should also store the incident radiance for all incident directions. Memory storage can be reduced with projection techniques using spherical harmonics or other basis functions. These techniques provide good results for low shininess BRDFs. However, they get impractical for shininess of even moderate value, since the number of projection coefficients increases drastically. We have proposed a new radiance caching method that handles highly glossy surfaces while requiring a low memory storage. Each cache record stores a coarse representation of the incident illumination thanks to a new data structure, called Equivalent Area light Sources, capable of handling fuzzy mirror surfaces. In addition, our method proposes a new simplification of the interpolation process, since it avoids the need for expressing and evaluating complex gradients. This work has been published in the journal *The Visual Computer* [7].

### 5.3 Bayesian Monte Carlo

**Participants:** Ricardo Marques, Christian Bouville, Kadi Bouatouch.

Bayesian Monte Carlo (BMC) is a promising integration technique which considerably broadens the theoretical tools that can be used to maximize and exploit the information produced by sampling, while keeping the fundamental property of data dimension independence of classical Monte Carlo (CMC). Moreover, BMC uses information that is ignored in the CMC method, such as the samples' position and prior stochastic information about the integrand, which often leads to better integral estimates. Nevertheless, the use of BMC in computer graphics is still in an incipient phase and its application to more evolved and widely used rendering algorithms remains cumbersome. We have proposed to apply BMC to a 2-level adaptive sampling scheme for illumination integrals. We have also proposed an efficient solution for the level-2 quadrature computation and showed that our adaptive BMC method overcomes adaptive quasi-Monte Carlo in terms of image error and high frequency noise. This work has been presented at the Eurographics conference in 2016 [14].

### 5.4 Quasi Monte Carlo

**Participants:** Ricardo Marques, Christian Bouville, Kadi Bouatouch.

Quasi-Monte Carlo (QMC) methods exhibit a faster convergence rate than that of classic Monte Carlo methods. This feature has made QMC prevalent in image synthesis, where it is frequently used for approximating the value of spherical integrals (e.g. illumination integral). The common approach for generating QMC sampling patterns for spherical integration (used in global illumination) is to resort to unit square low-discrepancy sequences and map them to the hemisphere. However such an approach is suboptimal as these sequences do not account for the spherical topology and their discrepancy properties on the unit square are impaired by the spherical projection. So, we are interested in directly sampling the hemisphere for global illumination purposes.

QMC (Quasi Monte Carlo) are extensively used in rendering algorithms but among the

many possible techniques proposed in the literature, it is very difficult to predict what will be their performances when applied to rendering. As the benefits of QMC compared to classic Monte Carlo depend on the integrand smoothness, this factor must necessarily be taken into account in a performance criterion. Furthermore, most QMC techniques are originally designed for sampling the unit square or the unit cube whereas the illumination integral is fundamentally a hemispherical integral. Our goal is thus to propose a theoretical framework that enables to predict the performances of QMC techniques applied to global illumination to compute the illumination integral. For this purpose, we use a spherical Fourier analysis of the illumination integral considering both diffuse and glossy reflection cases. We show that the integration error can be broken down into two distinct components which have been described as zonal and anisotropic. We then define a performance criterion that uses the Sobolev spaces theory to characterize the smoothness of integrands in the frequency domain. The proposed theoretical framework is applied to various QMC techniques so as to analyze and predict their performances. These predictions are confirmed by experimental global illumination results. This work has been submitted to EGSR'2017 (EuroGraphics Symposium on Rendering).

## 5.5 Shape and Reflectance Reconstruction from RGB-D Images

**Participants:** Matis Hudon, Rémi Cozot, Kadi Bouatouch.

We have proposed a method for recovering the shape (geometry) and the diffuse reflectance from an image (or video) using a hybrid setup consisting of a depth sensor (Kinect), a consumer camera and a partially controlled illumination (using a flash). The objective was to show how sequential illumination is useful for shape and reflectance recovery. A pair of two images are captured: one non flashed image NFI (image under ambient illumination) and a flashed one FI. A pure flashed image PFI is computed by subtracting the NFI image from the FI image. We used the resulting PFI image to recover the shape and the reflectances of the captured scene. We have proposed a novel and fast algorithm to recover a finer geometry (from the noisy depth map provided by the Kinect) and precise reflectances. The algorithm is iterative and converge rapidly to the desired values. More precisely, knowing the the lighting (flash light source) we used a local illumination model to extract information on the normals and the diffuse reflectance of the objects of the captured scene. This has been presented at the VISAPP conference in 2016 [13, 2].

## 5.6 Automatic Light Compositing

**Participants:** Matis Hudon, Rémi Cozot, Kadi Bouatouch.

Lighting is a key element in photography. Professional photographers often work with complex lighting setups to directly capture an image close to the targeted one. Some photographers reversed this traditional workflow. Indeed, they capture the scene under several lighting conditions, then combine the captured images to get the expected one. Acquiring such a set of images is a tedious task and combining them requires some skill in photography. We propose a fully automatic method, that renders, based on a 3D reconstructed model (shape and albedo), a set of images corresponding to several lighting conditions. The resulting images

are combined using a genetic optimization algorithm to match the desired lighting provided by the user as an image. This has been presented at the DMIAF conference in 2016 [12, 2].

### 5.7 Multivariate Generalized Gaussian Distribution

**Participants:** Hristina Hristova, Olivier Le Meur, Rémi Cozot, Kadi Bouatouch.

Multivariate generalized Gaussian distributions (MGGDs) have aroused a great interest in the image processing community thanks to their ability to describe accurately various image features, such as image gradient fields. However, so far their applicability has been limited by the lack of a transformation between two of these parametric distributions. We have proposed a novel transformation between MGGDs, consisting of an optimal transportation of the second-order statistics and a stochastic-based shape parameter transformation. We have employed the proposed transformation in both color and gradient transfers between images. We have also proposed a new simultaneous transfer of color and gradient, which we have applied for color correction. This work has been submitted to TVCG [6], its currently status is: major revision.

### 5.8 HDR Image Recovery from Flash and Non-Flash Image

**Participants:** Hristina Hristova, Olivier Le Meur, Rémi Cozot, Kadi Bouatouch.

We have proposed a novel method for creating HDR images from only two images - flash and non-flash images. Our method consists of two main steps, namely brightness gamma correction and bi-local chromatic adaptation transform (CAT). The brightness gamma correction performs series of increases and decreases of the non-flash brightness and yields multiple images with various exposure values. The bi-local CAT enhances the quality of each computed image by recovering missing details, using information from the flash image. The final multi-exposure images are then merged together to compute an HDR image. An evaluation showed that our HDR images, obtained by using only two LDR images, were close to HDR images, obtained by combining five manually taken multi-exposure images. Our method does not require the usage of a tripod and it is suitable for images of non-still objects, such as people, candle flames, etc. This work has been accepted to be presented at the CGI conference [10] in 2017 and will be also published in The Visual Computer Journal.

### 5.9 CAT-based Guided Filter

**Participants:** Hristina Hristova, Olivier Le Meur, Rémi Cozot, Kadi Bouatouch.

We have proposed a new guidance filter, based on color perception through a chromatic adaptation model. Our method consists of a patch-wise linear transformation, which transfers details from a guidance image to an input image. The amount of transferred details is controlled by a novel chromatic adaptation transform (CAT), called bi-local CAT, embedded in our method. The bi-local CAT contributes to the detail recovery from the guidance image as well as to the preservation of the input reflections and shadows. Our CAT-based filter is applied in various image processing domains, such as image denoising, image deblurring, texture transfer,

detail enhancement, skin beautification, etc. This work has been submitted to the journal CVIU [5], its status is: under review.

### 5.10 Perceptual Metric for Color Transfer

**Participants:** Hristina Hristova, Olivier Le Meur, Rémi Cozot, Kadi Bouatouch.

We have proposed a perceptual model for evaluating results from color transfer methods. We have conducted a user study which provides a set of subjective scores for triples of input, target and result images. Then, for each triple, we have computed a number of image features which objectively characterize a color transfer. To describe the relationship between these features and the subjective scores, we have built a regression model with random forests. An analysis and a cross-validation has shown that the predictions of our model were highly accurate. This work has been submitted to the ICIP conference [11], its status is: under review.

### 5.11 HDR Imaging

**Participants:** Cambodge Bist, Rémi Cozot.

High Dynamic Range (HDR) is the latest video format for display technology and there is a strong industrial effort in deploying an HDR capable ecosystem in the near future. Initial HDR consumer displays will operate on a peak brightness of about 500-1000 nits while in the coming years display peak brightness is expected to go beyond 1000 nits. However, professionally graded HDR content can range from 1000 to 4000 nits. As with Standard Dynamic Range (SDR) content, we can expect HDR content to be available in variety of lighting styles such as low key, medium key and high key video. This raises concerns over tone-compatibility between HDR displays especially when adapting to various lighting styles. It is expected that dynamic range adaptation between HDR displays uses similar techniques as found with tone mapping and tone expansion operators. We have surveyed simple tone mapping methods of 4000 nits color-graded HDR content for 1000 nits HDR displays. We have also investigated tone expansion strategies when HDR content graded in 1000 nits is displayed on 4000 nits HDR monitors. We have concluded that the best tone reproduction technique between HDR displays strongly depends on the lighting style of the content [9].

However, most existing video content today are in Standard Dynamic Range (SDR) format and there is a growing necessity to upscale this content for HDR displays. Tone expansion, also known as inverse tone mapping, converts an SDR content into an HDR format using Expansion Operators (EOs). We have shown that current state-of-the-art EO do not preserve artistic intent when dealing with content of various lighting style aesthetics. Furthermore, we have conducted a series of subjective user studies evaluating user preference for various lighting styles as seen on HDR displays. This study showed that tone expansion of stylized content takes the form of gamma correction and we have proposed a novel EO that adapts the gamma value to the intended style of the video. However, we have also observed that a power function-based expansion technique caused changes in terms of color appearance. To solve this problem, we have proposed a simple color correction method that can be applied after tone

expansion to emulate the intended colors in HDR. We have validated our method through a perceptual evaluation against existing methods. In addition to this, our work targeted 1000 nits HDR displays and we have presented a framework aligning our method in conformance with existing SDR standards and the latest HDR TV standards [8, 3].

## 6 Contracts and Grants with Industry

### 6.1 Contracts

We had 3 CIFRE grants (2 from Technicolor, 1 from Harmonic) in 2016 and have two CIFRE grants (1 from Technicolor, one from Harmonic) in 2017.

## 7 Other Grants and Activities

### 7.1 International Collaborations

We have several collaborations with other laboratories and universities: University of Central Florida (UCF) in Orlando (US), Technical University of Prague (Czech Republic), University of Minho in Braga (Portugal), University of Pretoria (South Africa). Within the framework of these collaborations, several PhD students have been or are jointly supervised.

We are about to establish collaborations with the Image Processing for Enhanced Cinematography group from the university of Pompeu Fabra in Barcelona, Spain.

### 7.2 National Collaborations

## 8 Dissemination

### 8.1 Involvement in the Scientific Community

Most of the team members have published in:

- high level journals: ACM Trans. On Graphics, IEEE Trans. Visualization and Computer Graphics, IEEE Comp. Graphics and Applications, Computer Graphics Forum, Journal of Graphics Tools, The Visual Computer, etc.
- and high level conferences: SIGGRAPH (presentation in 2017 of our paper published in ACM TOG journal), EGSR, Pacific Graphics, IEEE Virtual Reality, Computer Graphics International, Web3D, Expressive, etc.

They have been reviewers for several conferences and symposia such as Siggraph, Eurographics Pacific graphics, etc., and for journals such as ACM TOG, IEEE TVCG, The Visual Computer, Computer Graphics Forum, etc.

Kadi Bouatouch is an associate editor of the journal The Visual Computer. He has also been external examiners for several PhD in Europe (England, Germany, Belgium, The Netherlands, Spain, Cyprus) and the United States (UCF, Utah). He was also the co-chair of the second international conference and SME workshop of the IC-1005 HDRI cost action in 2014.

Christian Bouville and Kadi Bouatouch have been the co-chairs of the Web3D'2003 conference which has been held in Saint Malo, France. We have also founded the Eurographics Workshop on Rendering in 1990. This workshop became EGSR (EuroGraphics Symposium on Rendering) in 2003.

We have participated in a book on HDR [1]. We gave a tutorial at the Eurographics'2014 conference in Strasbourg (France) and at VISIGRAPP'2017 in Porto (Portugal). These tutorials are concerned with Bayesian and Quasi Monte Carlo Spherical Integration for Illumination Integrals. We also gave, in 2014, a tutorial within the framework of the Training School of the IC-10005 HDRi cost action ..

## 8.2 Teaching

Kadi Bouatouch is Professor at ISTIC, university of Rennes 1. He gives courses on programming (Mathematica, JAVA) and on computer graphics. He was responsible for Digital Image track of the Master of computer science delivered by the university of Rennes 1.

Rémi Cozot is an assistant professor at ESIR, university of Rennes 1. He is an associate editor of the journal The Visual Computer. He gives courses on programming (JAVA, C++) and on computer graphics.

## 9 Bibliography

### Major publications by the team in recent years

- [1] J. BROUILLAT, C. BOUVILLE, B. LOOS, K. B. C. HANSEN, "A Bayesian Monte Carlo Approach to Global Illumination", *Computer Graphics Forum* 28, 8, 2009.
- [2] P. GAUTRON, K. BOUATOUCH, S. PATTANAIK, "Temporal Radiance Caching", *IEEE Transactions on Visualization and Computer Graphics* 12, 5, 2007.
- [3] A. GRUSON, M. RIBARDIERE, R. COZOT, "Eye-Centered Color Adaptation in Global Illumination", *Computer Graphics Forum* 32, 7, 2013, p. 111–120.
- [4] J. KRIVANEK, P. GAUTRON, S. PATTANAIK, K. BOUATOUCH, "Radiance Caching for Efficient Global Illumination Computation", *IEEE Transactions on Visualization and Computer Graphics* 11, 5, September-October 2005, p. 550–561.
- [5] R. MARQUES, C. BOUVILLE, M. RIBARDIERE, L. SANTOS, K. BOUATOUCH, "Spherical Fibonacci Point Sets for Illumination Integrals", *Computer Graphics Forum* 32, 8, 2013.
- [6] M. RIBARDIERE, S. CARRE, K. BOUATOUCH, "Adaptive Records for Irradiance Caching", *Computer Graphics Forum* 30, 6, 2011, p. 1603–1616.

### Books and Monographs

- [1] R. BOITARD, R. COZOT, K. BOUATOUCH, *Video Tone Mapping of book: From Acquisition to Display and Applications*, Academic Press, Elsevier, 2016.

## Doctoral dissertations and “Habilitation” theses

- [2] M. HUDON, *Active illumination high speed Image acquisition and recovery of shape and albedo*, PhD Thesis, University of Rennes 1, October 2016.

## Articles in referred journals and book chapters

- [3] C. BIST, R. COZOT, G. MADEC, X. DUCLOUX, “Tone expansion using lighting style aesthetics”, *Computer and Graphics* 62, 2017, p. 77–86.
- [4] A. GRUSON, M. RIBARDIERE, M. SIK, R. C. J. VORBA, K. BOUATOUCH, J. KRIVANEK, “A Spatial Target Function for Metropolis Photon Tracing”, *ACM Trans. On Graphics* 6, 4, February 2017.
- [5] H. HRISTOVA, O. L. MEUR, R. COZOT, K. BOUATOUCH, “Multi-purpose CAT-based guidance filter: submitted to CVIU”, *submitted to the CVIU journal, under review*, 2017.
- [6] H. HRISTOVA, O. L. MEUR, R. COZOT, K. BOUATOUCH, “Transformation of the multivariate generalized Gaussian distribution for image editing”, *submitted to IEEE TVCG, under revision*, 2017.
- [7] M. OMIDVAR, M. RIBARDIERE, S. CARRE, D. MENEVEAUX, K. BOUATOUCH, “A radiance cache method for highly glossy surfaces”, *The Visual Computer* 32, 10, October 2016.

## Publications in Conferences and Workshops

- [8] C. BIST, R. COZOT, G. MADEC, X. DUCLOUX, “Style Aware Tone Expansion for HDR Displays”, *in: GRAPHIC INTERFACE*, Victoria, British Columbia, Canada, June 2016.
- [9] C. BIST, R. COZOT, G. MADEC, X. DUCLOUX, “Tone compatibility between HDR displays”, *in: Proceeding of Applications of Digital Image Processing XXXIX, SPIE 2016*, San Diego, California, United States, June 2016.
- [10] H. HRISTOVA, O. L. MEUR, R. COZOT, K. BOUATOUCH, “High-Dynamic-Range Image Recovery from Flash and Non-Flash Image Pairs”, *in: The Visual Computer Journal, also presented at CGI’2017*, Yokohama, Japan, June 2017.
- [11] H. HRISTOVA, O. L. MEUR, R. COZOT, K. BOUATOUCH, “Perceptual metric for color transfer methods”, *in: submitted to ICIP’2017 conference*, Beijing, China, September 2017.
- [12] M. HUDON, R. COZOT, K. BOUATOUCH, “Automatic Light Compositing using Rendered Images”, *in: DMIAF*, July, Santorini, Greece, July 2016.
- [13] M. HUDON, A. GRUSON, P. KERBIRIOU, R. COZOT, K. BOUATOUCH, “Shape and Reflectance from RGB-D Images Using Time Sequential Illumination”, *in: VISAPP*, Roma, Italy, February 2016.
- [14] R. MARQUES, C. BOUVILLE, L. SANTOS, K. BOUATOUCH, “2-Level Adative Sampling for Illumination Integrals using Bayesian Monte Carlo”, *in: Eurographics*, Lisbon, Portugal, May 2016.