Project-Team FRVSense

Fast Rendering and Visualization Sense

Rennes

| *Activity Report*

2012

1 Team

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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
   - HDR and tone mapping
   - Multi-view rendering on stereoscopic and auto-stereoscopic display devices;

3. Image based rendering and modeling

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. Regarding cinematographic relighting, our goal is to devise an algorithm for relighting images of an animation sequence. Changing the parameters of light sources and playing back the animation could be done interactively. Following the work of Haÿsan et al. [MEFK08] we want to formalize the problem of animation relighting using a transfer tensor. We want to propose an adaptive method for the tensor evaluation and a practical optimization of the clustered principal component analysis (CPCA) used for tensor compression.

  For global illumination we have proposed another integration procedure known as Bayesian Monte Carlo integration (BMC)[O'H87]. As opposed to importance sampling methods, BMC does not require the samples to be drawn from a predefined pdf and does take into account samples location. The price to pay for this is a higher computational cost per samples but in a recent paper[BBL+09], 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 specular component and experiment this solution for real time environment map rendering. An important aspect of this work will be the integration of prior knowledge. We are also investigating solutions for spatio-temporal sampling and interpolation as mentioned above. We think that BMC can provide a very powerful framework in which both procedures of approximation and integration can be merged, thus leading to very efficient rendering methods.

- Color and visual perception
  - Color appearance models and tone mapping
    Our main objective is to propose approaches allowing to combine global illumination

[MEFK08] H. M., V.-A. E., P. F., B. K., "Tensor Clustering for Rendering Many-Light Animations", *Computer Graphics Forum 27*, 4, 2008.

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

[BBL+09] J. Brouillat, C. Bouville, B. Loos, C. Hansen, K. Bouatouch, "A Bayesian Monte Carlo Approach to Global Illumination", *Computer Graphics Forum 28*, 8, 2009, p. 2315–2329, http://dx.doi.org/10.1111/j.1467-8659.2009.01537.x.

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 botom-up approaches in the context virtual reality[HBO+10,HLC+10]. We have also proposed and evaluated methods to enhance visual feedback by adding a depth of field blur in VR applications[HLCC08]. In the short-term, our work will focus 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 study of new methods for improving visual comfort and perception in the specific context of auto-stereoscopic devices.

  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.

- Multi-view rendering
  Our goal in this project is to focus our research on the problem of real time multiview rendering of 3D scenes. The real time constraint is particularly challenging when it comes to rendering 256 views with a global illumination model. Such performance cannot be obtained without some pre-computation, which impacts visualization interactivity because some scene model characteristics (object attributes, light source position,É) will not be allowed to change and the navigation will be restricted.

- Image based rendering and modeling
  Our objective is to devise and develop a system that:

  - Offers a single navigation mode (only 3D models, no mix of 2D/3D models)) for global and immersive views from a small set of photographs,
  - Makes possible free navigation (the camera placement will not be constrained),
  - Needs only low-end devices (together or not with some GIS data) to recover a coarse 3D geometry of streets, buildings, shopping, etc, hence large scale deployment (cities) will be made possible,

[HBO+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+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.

– Is based on image based rendering and modeling to achieve these goals.

To this end, we want to recover a very coarse geometry from a single image or a set of images taken at different positions and orientations.

2.2 Key Issues

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 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[GBP07a,KGPB05].

Radiance caching has also been used to simulate multiple scattering within participating media[RCB11a]. 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,

[GBP07a] P. Gautron, K. Bouatouch, S. Pattanaik, "Temporal Radiance Caching", *IEEE Transactions on Visualization and Computer Graphics 12*, 5, 2007.

[KGPB05] J. KrivÃ¡nek, 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.

[RCB11a] M. Ribardiere, S. CarrÃ©, K. Bouatouch, "Adaptive Records for Volume Irradiance Caching", *in : Pacific Graphics'2011*, 2011.

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.

One of the important problems in computer cinematography is the lighting design in a scene.The designer places light sources in the scene, sets their parameters and renders the scene. He or she then adjusts the parameters of the light sources and renders the scene repeatedly until the desired lighting of the scene is obtained. That approach requires algorithms for image relighting to meet several requirements. Relighting of the image of the scene must be done interactively when changing the parameters of the light sources. The rendered image must contain all the details that the final rendering of the scene would contain. Relighting algorithms that produce an image different from the final rendering of the scenes cannot be used for lighting design. Another important requirement is the ability of the relighting algorithm to handle complex scenes. Such scenes show a high level of geometric detail, scene objects are represented by different types of material models and they are lit by various kinds of lighting sources. Furthermore, rendering of the scenes used for lighting design have to contain indirect lighting[EA04]. A number of relighting algorithms have been proposed to speed up the re-computation of the image of static scenes. Haÿsan et al.[HPB06] propose a relighting algorithm for recomputing images including both direct and indirect lighting. Indirect lighting computation is formulated as a linear transformation that transforms direct lighting on a large set of points to indirect lighting on another one. However, the algorithm can only be applied for image relighting for a fixed view point. Using the algorithm for lighting design in animation sequences is not supported. Lighting designed for one frame of the animation sequence does not provide any information about image lighting of the surrounding frames.

3.2 Bayesian 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 OÕHagan in 1987[O'H87], 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 Likehood 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 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).

[EA04] T. E., L. A., "An approximate global illumination system for computer generated films", *in : Siggraph*, SIGGRAPH, 2004.

[HPB06] M. Hasan, F. Pellacini, K. Bala, "Direct-To-Indirect Transfer for Cinematic Relighting", *in : Siggraph*, SIGGRAPH, 2006.

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

3.3 Color and Visual Perception

Keywords: Color appearence 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 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.

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+10]

Many woks also deal with chromatic adaptation. They belong to different research fields: computer graphics, color science, computer vision, etc [Fai91b,Fai91a,VK70,WW09].

In our context, the aim of chromatic adaptation is to recover the color appearance of objects as if the user was within a 3D scene (as if he sees directly the seen). 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]. These color appearance models need the focussed point when the aim is to provide accurate results. This is made possible thanks to visual attention models

[RWD+10] E. Reinhard, G. Ward, P. Debevec, S. Pattanaik, W. Heidrich, K. Myszkowsk, *High Dynamic Range Imaging*, Morgan Kaufmann Publishers, San Francisco, USA, 2010.

[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.

[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.

whose aim is to estimate the gaze direction, the movement and the behavior of the user. The visual attention models require that the rendered image is perceptually correct. This is a challenge that has to be taken up. Nowadays first algorithms deliver a rather good estimate of the focussed point in the context of 3D world [ITT05,LDC06]. Their main limitation consists of the fact that they do not deal with high dynamic range and complex viewing conditions.

According to this the main challenge consist in mixing the HVS features (luminance and chromatic adaptation, color appearance, etc.), the human gaze behavior, the viewing conditions of the user's avatar in the 3D world and of the user in the real world (display features and user viewing conditions), in the context dynamic scenes (realtime walkthrough for example).

Multiview Rendering Since the outset of research in global illumination, most of the research works in this domain has focused on the rendering of a single image at a time. But recently, there has been a growing interest in the problem of rendering several views of a scene taken at closed distances in the spatio-temporal domain while efficiently exploiting image coherence. This is mainly due to recent developments of two well-known research domains of computer graphics and virtual reality:

- 3D stereoscopic visualization is booming again with the advent of 3DTV at home. 3D displays are becoming affordable for consumer mass market with an offering ranging from 3-D LCDs requiring glasses to multiview autostereoscopic displays. From the computational point of view, stereoscopic visualization only requires the rendering of two views, which can be sustained by most state-of-the-art graphic boards. However, to avoid the discomfort caused by glasses, autostereoscopic technologies have aroused a considerable research effort and the commercial offering is constantly expanding. These technologies allow glass-free stereoscopic visualization in an angular range of up to 360¡ but they require the rendering of a much greater number of views than basic two-view stereo displays[BWS+07]. Presently commercialized autostereoscopic displays use either a parallax barrier or a lenticular technology with a 9-view limit in either case; however some research prototypes[DML+01] can display as much as 256 views[TN10], which requires specific rendering techniques.

- Network-based 3D graphics and especially Web-based applications have regained interest these last years for various reasons: ever increasing 3D data complexity that measures

[ITT05] L. ITTI, "Quantifying the contribution of low-level saliency to human eye movements in dynamic scenes", *Visual Cognition 12*, 2005.

[LDC06] P. LONGHURST, K. DEBATTISTA, A. CHALMERS, "A GPU based saliency map for high-fidelity selective rendering", *in : 4th international conference on Computer graphics, virtual reality, visualisation and interaction in Africa*, 2006.

[BWS+07] P. Benzie, J. Watson, P. Surman, I. Rakkolainen, K. Hopf, H. Urey, V. Sainov, C. von Kopylow, "A Survey of 3DTV Displays: Techniques and Technologies", *IEEE Transactionns on Circuits and Systems for Video Technology 17*, 11, 2007, p. 1647–1658.

[DML+01] N. A. Dodgson, J. R. Moore, S. R. Lang, G. Martin, P. Canepa, "A 50" Time-Multiplexed Autostereoscopic Display", *in : Proc. SPIE Stereoscopic Displays & Applications XI*, *3957*, SPIE, p. 177–183, January 2001.

[TN10] Y. Takaki, N. Nago, "Multi-projection of lenticular displays to construct a 256-view super multi-view display.", *Opt Express 18*, 9, Apr 2010, p. 8824–8835.

in Gigabytes today, better protection of property rights on secure servers, exponential growth of services for light mobile clients with limited resources, emergence of Cloud Computing services,É Network-based 3D applications may have very different requirements in terms of real time, navigation, interactivity, rendering quality and 3D data complexity. However, the used rendering techniques must make the most of spatio-temporal coherence through appropriate pre-computed data structures so as to reduce network latency effects and to cope with limited computational resources.

Though both problems cannot be solved without considering hardware architecture specificities, they raise the same fundamental issue of fast and efficient computation of closed viewpoints in the spatio-temporal domain. This research topic is not new in computer graphics and the problem of exploiting spatio-temporal coherence to speed up computation time has been extensively addressed in the literature e.g.[GBP07b]. However, with the constraints of the applications mentioned above, the complexity and the dimensionality of the problem has considerably changed, which leads us to re-examine the problem in depth.

3.4 Image Based Modeling and Rendering

Keywords: Image based rendering, reconstruction, navigation.

In a 3D environment, complex navigation (or complex walkthrough) is characterized by the capacity of the user to move on from a global view of the environment (aerial view) to a local and immersive view (close view). Navigation applications, such as Google Earth[Eara], offer a global view of an environment. In this kind of application, free navigation also allows us to progressively move on to a local view, but the quality of the database does not make this view immersive. This is due to the fact that these applications have to change the navigation mode from a 3D view to a 360 degree 2D panoramic images representing a local view. Here the term immersive means: a freedom of movement (in contrast to a strongly constrained movement using only photographs) and a perception of real 3D (perception of relief). Complex navigation means: possibility of scale change (multi-scale view, view of a city or a street or the interior of a building, free move of the camera). At present, some systems rely on the capture of a huge number of photographs taken at the ground level. These high quality 2D views ensure immersive views but do not allow free navigation, only point-to-point navigation is possible. An example of this kind of system is Google StreeView[Vie].

Photosynth[Pho] provides a new navigation system within a collection of photographs of the same scene. It can thus be applied to urban zone. By nature however, it only provides the user with local navigation. It is based on the construction of a 3D point cloud from unordered photographs[GSC+07], and allows navigation within this cloud. The raw images are directly

[GBP07b] P. Gautron, K. Bouatouch, S. Pattanaik, "Temporal Radiance Caching", *IEEE Transactions on Visualization and Computer Graphics 13*, 5, 2007, p. 891–901.

[Eara] G. Earth, "http://earth.google.com", `http://earth.google.com`.

[Vie] G. S. View, "http://maps.google.com/help/maps/streetview", `http://maps.google.com/help/maps/streetview`.

[Pho] Photosynth, "http://photosynth.net", `http://photosynth.net`.

[GSC+07] M. Goesele, N. Snavely, B. Curless, H. Hoppe, S. M. Seitz, "Multi-View Stereo for

mapped on the 3D points for visualization purposes. Works based on this core algorithm show how it is possible to extract characteristic parts of touristy zones to build a visual summary, find a significant walking path through a given zone to build relevant virtual tours, or extract the most significant parts of a photographs database. The navigation system developed in Earth Mine [Earb] can be seen as an evolution of Google Street ViewÕs. Local ground navigation is still constrained by successive and sparse panoramic nodes. However, their acquisition system provides 3D information for each pixel of the panoramas. One can thus click on whichever image zone to jump directly to the nearest panoramic zone. Parallel to this local viewing mode, the interface displays an aerial view of the zone, thus allowing global and local navigation at the very same time. But both modes are separate and there is no visualization link between them.

Numerous solutions are now available to model urban zones[DYB98,SMB07,MZWVG07].

4 Application Domains

4.1 Applications

Participants: all participants.

The applications of our works are:

- 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 Camera placement

Participants: Billal Merabti, Rémi Cozot, Kadi Bouatouch.

Community Photo Collections", *Computer Vision, IEEE International Conference on 0*, 2007, p. 1–8.

[Earb] Earthmine, "http://www.earthmine.com", `http://www.earthmine.com`.

[DYB98] P. Debevec, Y. Yu, G. Boshokov, "Efficient View-Dependent Image-Based Rendering with Projective Texture-Mapping", *research report*, Berkeley, CA, USA, 1998.

[SMB07] G. Sourimant, L. Morin, K. Bouatouch, "Gps, Gis and Video Fusion for Urban Modeling", *in : Proceedings of Computer Graphics International Conference*, May-June 2007.

[MZWVG07] P. Müller, G. Zeng, P. Wonka, L. Van Gool, "Image-based procedural modeling of facades", *in : ACM SIGGRAPH 2007 papers*, *SIGGRAPH '07*, ACM, New York, NY, USA, 2007, `http://doi.acm.org/10.1145/1275808.1276484`.

The important advances in the quality and performances of 3D rendering allow to create 3D animated sequences in real-time with the aim to generate in real-time movies of cinematographic quality. However, the integration of 3D cinematographic elements (camera placement, light source placement, actor placement) requires the formalization of a knowledge that exists empirically in industry and in the literature. The approach that we adopt is to study, from real data (movies), the combination of framing, lighting and placement of actors, given elements of cinematographic style (duration of framings, their frequency, transition between framings, etc.) Our approach will provide an efficient computational model allowing the placement of actors, camera and light sources, with the aim of automatic staging satisfying elements of specified styles. This is work is performed with the collaboration of the Mimetic team of INRIA/IRISA in Rennes.

5.2 Bayesian Monte Carlo

Participants: Ricardo Marques, Christian Bouville, Kadi Bouatouch.

Bayesian Monte Carlo (BMC) techniques are widely used in the domain of Machine Learning, and relies on priors over the function of interest to improve Monte Carlo computations. We have used BMC integration to speed-up the final gathering operation needed in global illumination computation but only for diffuse objects. We have extended BMC to glossy surfaces and to scenes lit by a high frequency environment maps.

5.3 Multiview Rendering

Participants: Mohamed Djebbar, Christian Bouville, Kadi Bouatouch.

Multi-view auto-stereoscopic displays are now available at affordable cost and are getting widely used in virtual reality applications and 3D games. With their wide viewing zone, this type of display easily accommodates multiple viewers and does not require any head tracking. Real-time rendering on these displays poses a number of difficult problems: (1) real-time generation of several views of the same 3D scene, (2) choice of a particular sampling pattern of the displayed image requiring specific anti-aliasing procedures that results in a limitation of the usable depth range. We have proposed some solutions to the rendering of multiple views in real time relying on image based rendering while handling the occlusion and dis-occlusion problems using a frequency approach and light field sampling techniques.

5.4 HDR Imaging

Participants: Ronan Boitard, Mickael Ribardiere, Rémi Cozot, Kadi Bouatouch.

Several TMOs have been proposed over the last decade, from the simple global mapping to the more complex one simulating the human vision system. While these solutions work generally well for still pictures, they are usually less efficient for video sequences as they are source of visual artifacts. Only few of them can be adapted to cope with a sequence of images. In this paper we present a major problem that a static TMO usually encounters while dealing with video sequences, namely the temporal coherency. Indeed, as each tone mapper deals

with each frame separately, no temporal coherency is taken into account and hence the results can be quite disturbing for high varying dynamics in a video. We have proposed a temporal coherency algorithm that is designed to analyze a video as a whole, and from its characteristics adapts each tone mapped frame of a sequence in order to preserve the temporal coherency. This temporal coherency algorithm has been tested on a set of real as well as Computer Graphics Image (CGI) content and put in competition with several algorithms that are designed to be time-dependent. Results have shown that temporal coherency preserves the overall contrast in a sequence of images. Furthermore, this technique is applicable to any TMO as it is a post-processing that only depends on the used TMO. This work gave rise to a paper presented at the SPIE conference [1].

5.5 Global Illumination

Participants: All participants.

We have proposed a technique for efficiently rendering participating media with irradiance caching scheme using Monte Carlo ray tracing. We propose to extend 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. Our work on global illumination and visual perception gave rise to several publications [DBK11,RCB11b,RCB11c,GKsCBR11] and [4, 3, 5, 2].

Recall that computing the radiance at any point inside a participating medium amounts to

[DBK11] B. Duvenhage, K. Bouatouch, D. Kourie, "Exploring the Use of Glossy Light Volumes for Interactive Global Illumination", *Computer Graphics Forum 30*, 6, To appear in 2011, p. 1825–1836.

[RCB11b] M. RibardiÃ¨re, S. CarrÃ©, K. Bouatouch, "Adaptive Records for Irradiance Caching", *Computer Graphics Forum 30*, 6, 2011, p. 1603–1616.

[RCB11c] M. RibardiÃ¨re, S. CarrÃ©, K. Bouatouch, "Adaptive Records for Volume Irradiance Caching", *The Visual Computer 27*, 6-8, 2011, p. 655–664.

[GKsCBR11] V. Gassenbauer, J. Krivanek, K. B. snd Christian Bouville, M. Ribardiere, "mproving Performance and Accuracy of Local PCA", *Computer Graphics Forum 30*, 7, 2011, p. 1903–1910.

numerically solving this radiative transport of equation. Besides the irradiance cache method we have proposed, Discrete Ordinate Method (DOM) is a widely used solution method. DOM is computationally intensive. Fattal[Fat09] proposed Light Propagation Maps (LPM) to expedite DOM computation.We have proposed a streaming based parallelization of LPM to run on SIMD graphics hardware. Our method is fast and scalable. We report a 20x speed improvement by using our method as compared to Fattal's original method. Using our approach we are able to render 64x64x64 dynamic volume with multiple scattering of light at interactive speed on complex lighting.

6 Contracts and Grants with Industry

6.1 Contracts

We have been involved in the RUBI3 project financed by the region of Britanny. Our partners were two SMEs (Small and Medium enterprises) whose names are ARCHIVIDEO (in Rennes) and VIAMETRIS (in Laval). This project has as objective the navigation in reconstructed 3D worlds with global and immersive views. In addition, we are part of a new project (it has just been accepted) named Nevex, with industrial partners such as: Technicolor, TF1, and other companies involved in HDR acquisition and display. This last project is concerned with the design of a complete High Dynamic Range chain: acquisition, compression, transmission and display.

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), University of Utah in Salt Lake City (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 also in an european COST action whose leader is the university of Warwick, England.

7.2 National Collaborations

8 Dissemination

8.1 Involvement in the Scientific Community

Most of the team members have published in:

[Fat09] R. Fattal, "Participating media illumination using light propagation maps", *ACM Trans. Graph. 28*, 1, 2009, p. 1–11.

- high level journals: 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: EGSR, Pacific Graphics, IEEE Virtual Reality, Computer Graphics International, Web3D, 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).

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.

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 is responsible for Digital Image track of the Master of computer science delivered by the university of Rennes 1.

Remi Cozot is an assistant professor at ESIR, university of Rennes 1. He gives courses on programming (JAVA, C++) and on computer graphics.

9 Bibliography

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[2] C. Collin, M. Ribardière, R. Cozot, K. Bouatouch, "Progressive Volume Photon Tracing", *in : Siggraph Talk, Los Angeles*, ACM, 2012.

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