Improvement of global illumination methods for infrared rendering of outdoor scenes including targets

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ABSTRACT :

The SE-WORKBENCH workshop, also called CHORALE (French acceptation for "simulated Optronic Acoustic Radar battlefield") is used by the French DGA to perform multi-sensors simulations. The SE-WORKBENCH enables the user to create virtual and realistic multi spectral 3D scenes that may contain several types of target, and then generate the physical signal received by a sensor, typically an infrared (IR) sensor.

One of the current interests for the DGA is to be able to compute the IR signature of a target in its environment,which needs to be as representative as possible. The computation shall be done for various lighting conditions, both in the visible spectrum to assess military vehicles paints and in the infrared spectrum for improving stealthness.

SE-RAY-IR, the SE-WORKBENCH ray tracing kernel, enables to compute high realistic images in visible and infrared spectrum based on complex scenarios. The current version offers an advanced rendering algorithm, called Photon Mapping to handle complex multiple reflections. This is well suited to render confined scenes (i.e. building interiors, engines, ...) and to simulate light focalizations that could create unexpected hot points (useful for infrared signature simulations). This technique strongly raises the realism of the simulation; but it is actually difficult to use it for outdoor scene rendering because of huge memory requirements necessary to reduce the noise inherent to the method, for instance for the simulation of very wide light sources.

In this paper, we describe the recent evolutions of SE-RAY-IR that concerns improvements, firstly, of the physical materials description using a BRDF well fitted to complex materials and secondly of the rendering algorithm. We present a new highly configurable hybrid approach that takes the best-suited methods for each simulated phenomena among a set of literature rendering methods. It enables to compute highly realistic simulation of outdoor scenes, taking into account skylight multiple reflections, extended sources and glossy reflections.

INTRODUCTION

Visible, infrared, electromagnetic or acoustic sensor systems are usually difficult to simulate due to the complexity of the required synthetic environment modelling. The OKTAL-SE suite of software (SE-WORKBENCH [4] [5] [6]) enables the creation of realistic multi-spectral synthetic environments. The priority of the software is to provide physically accurate 3D databases and repository of physical materials. The usage of ray tracing and 3D graphic board techniques for the scene analysis enables the generation of high quality scenes of complex scenarios.

In last year OKTAL-SE paper for ITBM&S, of the development plans for SE-RAY-IR, the kernel ray tracing engine of the SE-WORKBENCH, were presented as well as first preliminary results, especially in the frame of global illumination rendering ([2] [6]) in both visible and infrared spectrum.

The current paper focuses on photon map algorithm enhancements, in correlation with SE-RAY-IR.

- Section 1 sums up the SE-WORKBENCH workshop main features.
- Section 2 gives a short description of the core photon map method applied within SE-WORKBENCH.
- Section 3 illustrates achieved results for test scenes in a close environment.
- Section 4 shows the interest of the photon map method applied to IR targets signature prediction.
- Section 5 presents new developments concerning "importance sampling" for advanced BRDF characterisation and rendering.
- Section 6 explains the limitation of photon map for open environment simulation.
- Section 7 presents solution implemented in SE-WORKBENCH with regard to open environment problem.

1 SE-WORKBENCH (CHORALE) SHORT PRESENTATION

SE-WORKBENCH also called CHORALE in France in the frame of DGA, is a full workbench that aims at simulating an E/O and/or RF synthetic environment. SE-WORKBENCH both contains modelling tools for synthetic environment modelling (SE-AGETIM is a sophisticated terrain modelling tool including a full GIS) and tools for rendering. The rendering process is dual. Either using ray tracing for advanced (but slow) physical rendering. Either using 3D graphic boards new technology (shaders …) for fast rendering. The SE-WORKBENCH main advantage is its validation settlement. The advanced rendering has been validated in the frame of Defence programs with the support of several eminent research centres. The great originality of SE-WORKBENCH is to be able to compute exactly the same image in real-time (OpenSceneGraph) and non-real-time (ray-tracing), sharing the same 3D database, the same physical materials, the same scenarios, the same atmospheric conditions and the same thermal definition. Comparison of such images is the best way to seriously quantify the limitation due to real time approach.

According to this policy, OKTAL-SE pushes the ray tracing quality to limits. In this context, the SE-WORKBENCH includes more and more sophisticated global illumination algorithms, taking advantage of complex definition of materials, atmosphere and thermal exchanges.

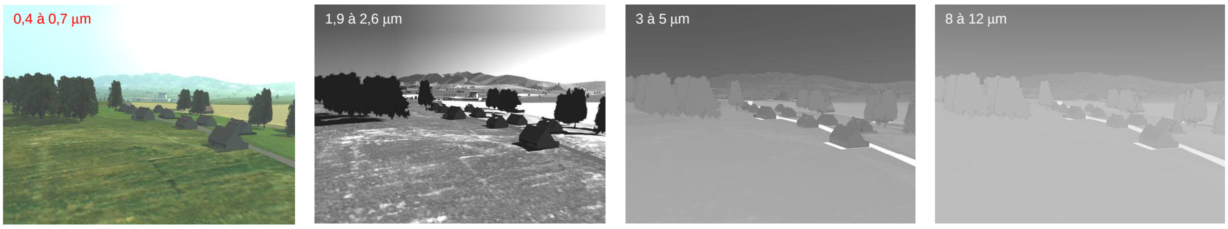

Figure 1: Typical spectral images generated with SE-RAY-IR in the visible and optronic spectrum.

2 PHOTON MAP METHOD INTRODUCTION

CURRENT BASIC ALGORITHM: PHOTON MAPPING

The photon mapping method [1, 3] was developed and validated in order to optimise the computations of multiple scattering effects in confined scenes (for example building interiors, engines...). In fact, these scenes are composed of closed spaces with little energy loss, and where the light sources (even if extended) are small.

The photon map method is a two passes method.
It first propagates light particles (or photons) through the scene and stores their impacts in a temporary data structure independent from the geometry.
The photons are emitted from surfaces considered as sources, due to their temperature (e.g. a hot object) or their emissive power (e.g. a lamp). The surface source is stochastically sampled with a uniform distribution, which density is controlled by the emissive power or temperature of the surface. Photons are traced through the scene, using ray tracing techniques. At photon-scene intersection locations, depending on the local surface material, photons are either absorbed or reflected.

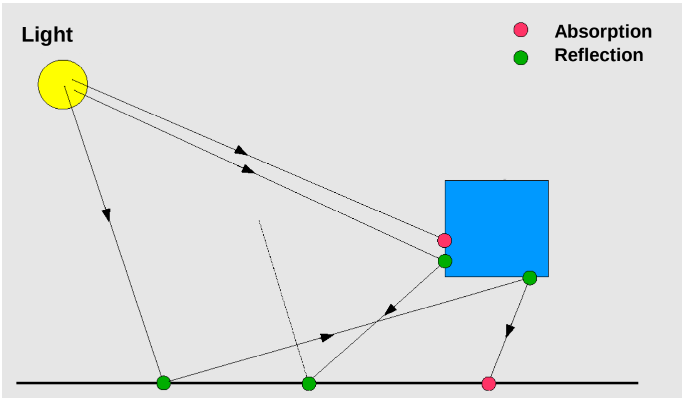

Figure 2: Principle of the photon mapping. Photons can be reflected or absorbed.

Then a gathering pass is performed by tracing primary rays through the scene, and computing the radiance of their intersection with the scene using the density estimation of the *k*. “*k”* is the number of nearest stored particles.

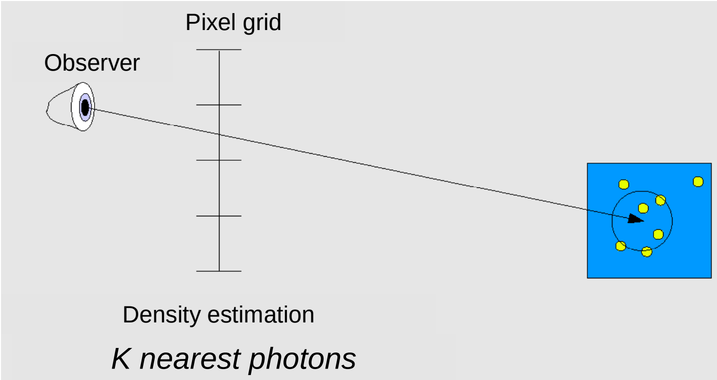

Figure 3: Collection of the “k” nearest photons and primary grid.

The method gives very good results for confined scenes. Actually, as few photons are lost (no intersection with the scene) and as photons multiple reflections are numerous, the necessary number of photons is (relatively) small. In most cases, a few million photons are needed.

A specificity of the SE-WORKBENCH is that this photon map method can also be applied to volumic participant media in open space. The approach is quite similar.

A first pass propagates photons inside the participant media. Depending on the local media, each photon is either absorbed, either reflected on a surface, either scattered (according to the phase function) within the participating media.

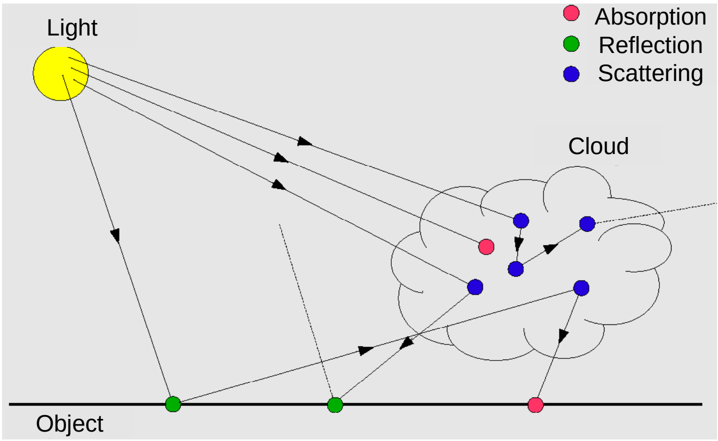

Figure 4: Photon interactions in the participating media

A second pass consists in a “ray marching” through the participating media, which accumulates energy on the path of the gathering ray.

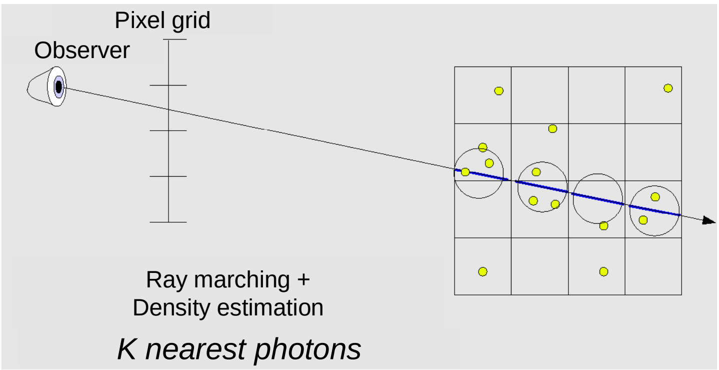

Figure 5: Photon gathering in the participating media.

The following images illustrate the scattering within clouds, rendered using photon maps.Different sun positions relative to the cloud according to the sensor are considered.

Figure 6: Results of cloud illumination by the sun using photon interaction with the participating media. The visible "energy" scattered in the sensor direction depends on the relative positions of the sun, the cloud and the sensor.

LIMITATIONS

The limitation of the photon maps method is its memory consumption. Indeed, if the number of photons used is not sufficient, the method suffers from low frequency noise. This noise disappears when the number of samples (photons) tends toward infinity. Of course, an infinity of photons cannot be used, then as many photons as the memory can store are thrown. A lot of improvements have been made recently within the SE-WORKBENCH that now enables to save a lot of photons.

Nevertheless, a multi-pass approach in SE-RAY-IR allows to significantly increase the accuracy of the results by making a compromise between memory consumption and rendering time.

The photon maps is well suited to render confined scenes and is the best in order to simulate light focalisations (i.e. caustics) that could create unexpected hot points (useful for infrared signature simulations). This technique strongly raises the realism of simulation; unfortunately, it cannot be used directly for outdoor scene rendering. The simulation of very extended light sources (like the sky) in vast scenes leads to unacceptable memory consumption that can't be achieved by most computers.

In standard methods, photons are emitted from light sources toward all the surfaces of the scene. In order to have a sufficient density on every scene surface, an enormous amount of photons must be stored, which cannot fit into most computers memory.
The second problem is that light sources are often considered to emit in all directions. As a consequence, a lot of photons are lost (no intersection with the scene), which results in unnecessary computations that increase rendering time.

The last limitation concerns the computation of very extended light sources contribution as the sky or the environment. In the previous version of the SE-WORKBENCH, the sky occlusions were neglected. By the way, no multiple skylight reflections were considered.

3 SOME RESULTS FOR TEST SCENES IN A CLOSE ENVIRONMENT

Several trails and validation tests have been made in close environment. The picture below illustrates the photon maps rendering within a close environment.

Figure 7: Result of the photon maps method in a confined environment, taking into account extend light sources and different types of materials.

Beyond these qualitative trials, several quantitative trials have also been made. One important test case is the "Cornell Box" scene.

The scene is an open box that contains two small cubes. All the objects of the scene have totally diffuse materials. These materials are spectrally defined. The left wall has a "red" material, the right wall a "green" material, and the other objects a "white" material. The scene is lighted by a square extended source that has a "yellow" emissive material.
The main interest of this scene is that Cornell University has done rela measurements on a "real equivalent" box. Therefore, it can be used to validate quantitatively global illumination methods like the photon maps.

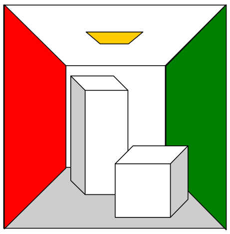

Figure 8: Schematic presentation of the Cornell Box with the extended light source (yellow) and the different objects and materials.

The quality of results mainly depends on the amount of photons.

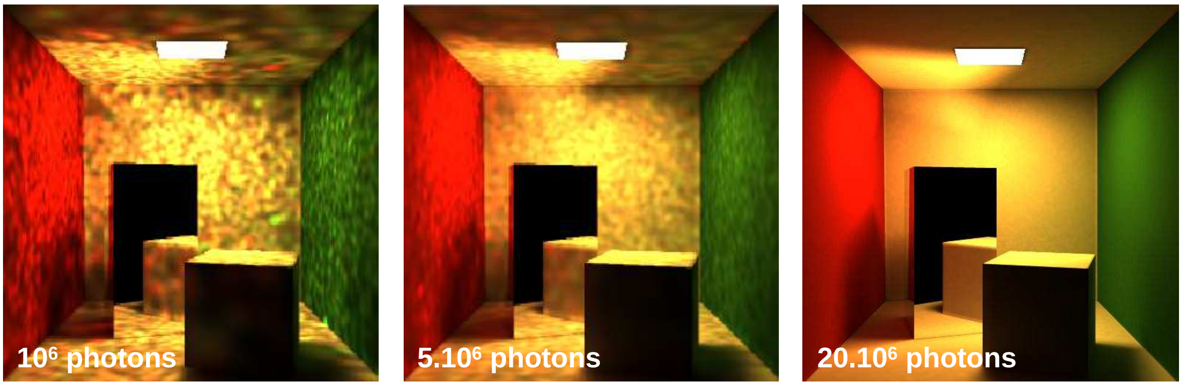

Figure 9: Result of the photon maps method applied to the Cornell Box as function of the number of photons.

4 PHOTON MAP METHOD EXTENDED TO TARGET IR SIGNATURE PREDICTION

The main application of this method within the SE-WORKBENCH, for infrared E/O application is currently the IR target signature prediction, typically for aircrafts and especially for helicopters. For some geometrically complex parts of aircrafts bodies (tail , intake, internal inlets, nozzle exit …), the photon maps method is adapted for multiple reflection simulation effects. It also can be interesting to render flares reflection effects on the target body. Concerning the exhaust plume, photon maps applied to the plume participant media enables to simulate light focalizations that could create unexpected hot points (caustics) or complex scattering effects in the plumes, typically for solid particles (e.g. missile signature).

Most of these effects are all the more perceptible as the specular component of the material is important. For this type of glossy materials, ray tracing can support standard photon mapping. The new version of the SE-WORKBENCH enables to merge photon mapping and rendering of glossy materials using bushes of rays around the specular direction.
The following test case illustrates this feature that can be very useful for IR target rendering, especially when enlighten by a set of hot flares.
The aim of this test is to validate quantitatively the rendering of the reflection of a pattern through glossy material reflections. The scene is made of a horizontal plate associated to a glossy material and a vertical plate mapped with diffuse materials of distinct colours.

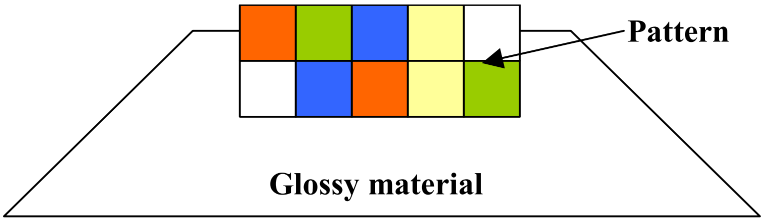

Figure 10: Presentation of the test pattern.

The scene is rendered using a glossy ray density of 16 rays per solid angle unit, with a minimum of 16 rays and a maximum of 32 rays.
The image below shows smooth reflections of the pattern on the horizontal plate.

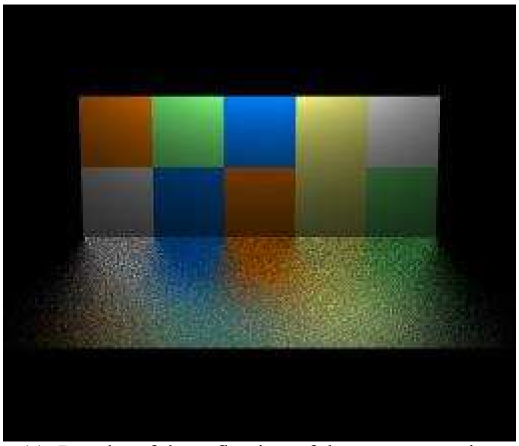

Figure 11: Results of the reflection of the test pattern image on a glossy material using photons maps method.

The previous test has been extended in order to validate quantitatively the rendering of the reflection of a pattern through glossy material reflections. Now, there are three distinct glossy materials. The test shows the influence of the glossy ray density according to the respective glossiness of the materials.

In this test case, the horizontal plate is associated to three distinct glossy materials with a shininess "n" of respectively 50, 1000 and 10000.

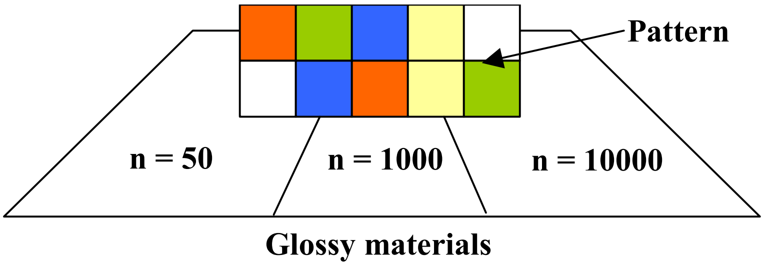

Figure 12: Presentation of the test pattern with several glossy materials.

The scene is rendered using a glossy ray density of 16 rays per solid angle unit, with a minimum of 8 rays and a maximum of 32 rays.

The resulting image shows smooth reflections of the pattern on the horizontal plate. The reflection of the pattern is distinct for each glossy material.

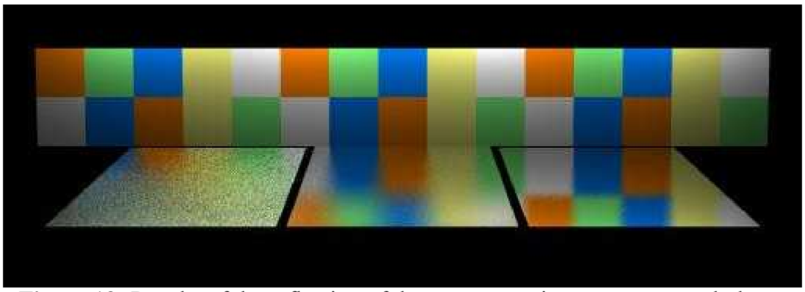

Figure 13: Results of the reflection of the test pattern image on a several glossy materials using photons maps method.

The test has been further extended in order to validate the reflection of a pattern through several glossy material reflections. For this purpose, the scene is made of two plates, one horizontal and one vertical, associated to a glossy material with shininess "n = 50". Another vertical plate is mapped with diffuse materials of distinct colours.

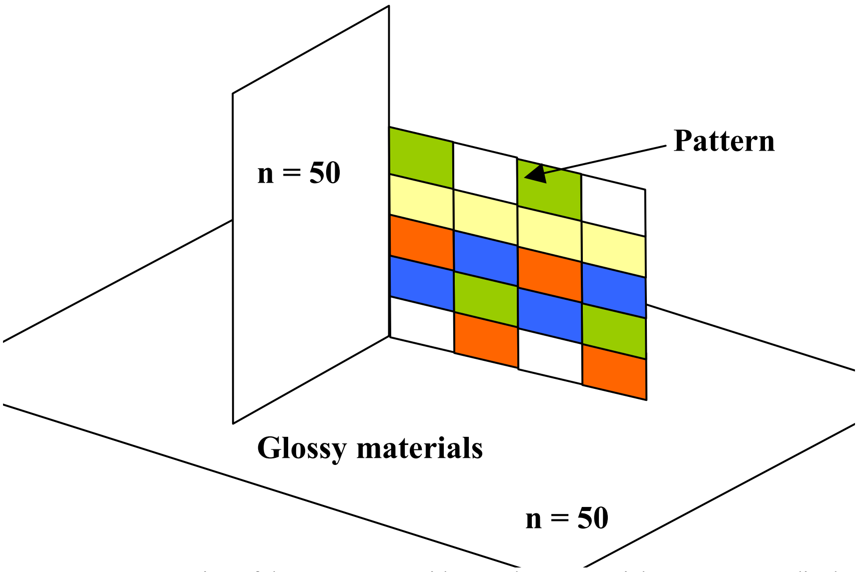

Figure 14: Presentation of the test pattern with one glossy material on two perpendicular surfaces.

The scene is rendered using a glossy ray density of 16 rays per solid angle unit, with a minimum of 8 rays and a maximum of 32 rays.

The resulting image shows smooth reflections of the pattern on the horizontal and vertical plates.

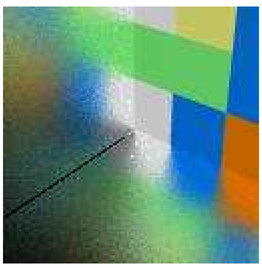

Figure 15: Results of the reflection of the test pattern image on a one glossy material and two perpendicular surfaces using photons maps method.

5 "IMPORTANCE SAMPLING" FOR ADVANCED BRDF

PREVIOUS MODEL

Materials are described by their radiative quantities i.e. self emitted radiance, transmittance, specular and diffuse BRDF. As many ray tracing algorithms, it formally uses a simple material model based on a canonical decomposition of the BRDF in more or less diffuse and specular components. Radiative data values are however described spectrally with an angular dependency (using textures).

LIMITATIONS

In the standard version of SE-RAY-IR, materials are defined using OKTAL-SE modelling file format (SDM). Actually, users can only define their own materials providing that they convert their data into SDM format. In this case, depending on the model to encode, there could be a loss of data due to this conversion.

Another limitation of the BRDF model is the decomposition of energy between so-called "specular" and "diffuse" components. It is a problem when random sampling of the BRDF is needed as required by the Photon Maps method. In this case, it would be better to have a material that is able to sample the incoming and/or outgoing hemisphere direction according to the repartition of energy in both specular and diffuse parts of the BRDF, without explicitly decomposing the model, which is implemented in the new version of SE-RAY-IR.

IMPLEMENTATION OF IMPORTANCE SAMPLING

Since the current model has limitation, it is still used and adapted to users who do not really dispose of BRDF accurate modelling or measurement. In this case, SE-RAY-IR uses an importance sampling technique based on a cosine weighting for the diffuse component (rather than a constant sampling) and a shininess lobe in the specular direction.

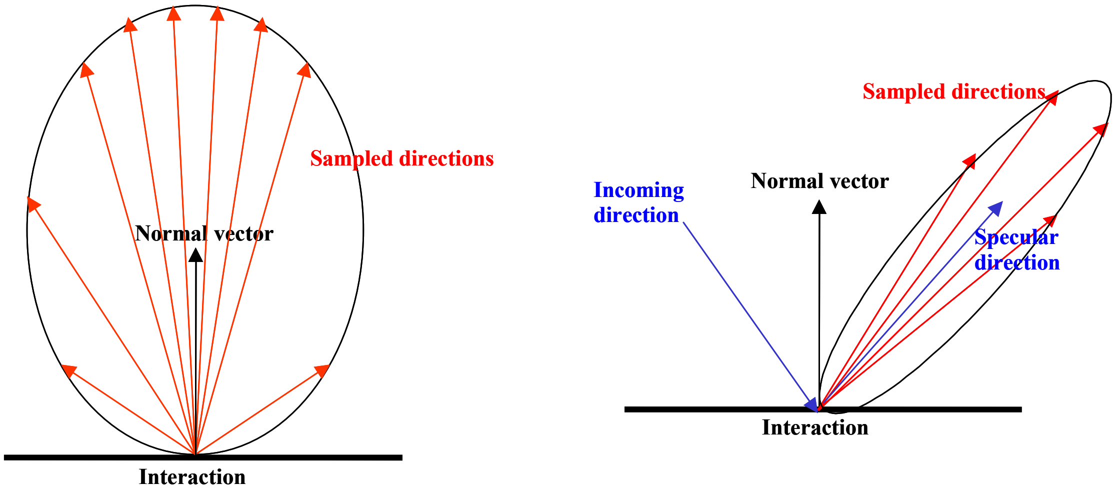

Figure 16: Principle of the decomposition of the BRDF into "diffuse" part (left image) and "specular" part (right image)

EVOLUTION

The main evolution concerns an improvement of the description of physical materials using a BRDF model that describes complex materials. In order to authorise the user to define a complex BRDF model without loss of data, the current version of SE-RAY-IR offers a generic material interface providing a function for each quantity needed to describe the material (i.e. self radiance, transmittance, BRDF ...).

The user through a dedicated toolkit can implement this interface. With this interface, the user is able to describe analytical models as well as to load measured data sets directly from proprietary formats. Of course, backward compatibility with existing materials is respected.

In order to optimize the memory payload due to heavy measurements, a compression model is under development. This compression authorizes to manage large amounts of BRDF data. It is based on a "wavelet compression algorithm" that also provides importance sampling capabilities. In this case, the importance sampling is generic; i.e. not only fitted to the canonical decomposition of BRDF into diffuse and specular components as told in the previous section. The sampling is adaptive to any shape of BRDF.

From a general point of view, the material evolution will enable the user to handle any kind of material from analytical models to measured data sets. It will take into account with a greater realism non-perfectly specular or diffuse materials, which are so-called “glossy” materials.

6 LIMITATION OF PHOTON MAP FOR OPEN ENVIRONMENT

For open environment (i.e. outdoor scene simulation), performance problem becomes critical when using photon mapping. Actually, considering sources at very far distance from the scene, or omni directional sources, the probability that a photon emitted never interacts with the scene is very high. Each of these photons, that are traced but not stored, are useless but still consume significant time.

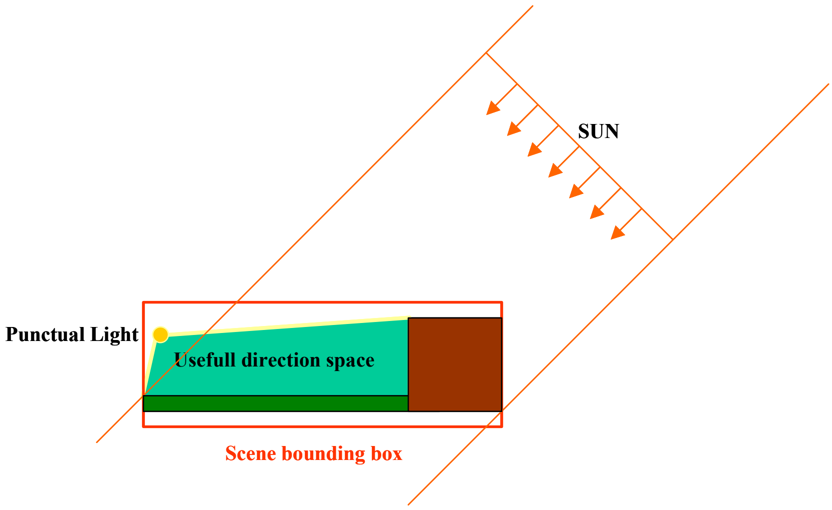

Figure 17: Principle of the user selection of the zone of interest.

7 SOLUTION FOR OPEN ENVIRONMENT SIMULATION

To optimize this drawback, the idea is to use several global illumination methods based on Monte Carlo ray tracing and melting them together instead of using only one of them (i.e. Photon Mapping). The interest of integrating all these methods in one hybrid method is to make the most of each method and avoid misusing it. Hence, it enables to withdraw their disadvantages while keeping their advantages.

The new version of SE-RAY-IR is able to handle the following phenomena using this innovative hybrid method:
- sky light occlusions,
- sky light multiple reflections,
- environment lighting,
- direct lighting of small extended light sources,
- indirect lighting of small extended light sources,
- sun indirect lighting.

For each phenomenon, different methods are used, which are adapted according to the specificities of these phenomena.

In the new version of SE-RAY-IR, distinction is made between so-call “extended sources” and “environment”. “Extended sources” are defined as surfacic sources with energy greater than a user defined threshold when “environment” corresponds to all the other surfaces of the scene plus the sky dome. “Extended sources” are typically made of polygons with hot temperature or particularly emissive material.

Direct illumination due to extended sources is computed using a hierarchical anti-aliased ray tracing approach. For a given interaction point, the surface is adaptively split according to the source masking.

Indirect illumination due to extended sources is computed using photon maps approach. Photons are casted from the extended surfaces, but only for important directions towards the scene and the photons storage is restricted to user defined local areas.

LOCAL PHOTON MAPS: OUTDOORS APPLICATION

The general principle consists in restricting the 3D zone of the scene where photons are effectively stored. Photons are traced through the whole scene but photon impacts are only stored in the user defined restricted zone.

A critical point of this method is to manage the transition between the photon maps zones and the other standard zones of the scene.

The method implemented in SE-RAY-IR consists in defining a "transition" zone in which computation is made both using photon maps and classical ray tracing. In this transition zone, pixel radiance is interpolated between photon map values and classical ray tracing values, according to the pixel position within the transition zone.

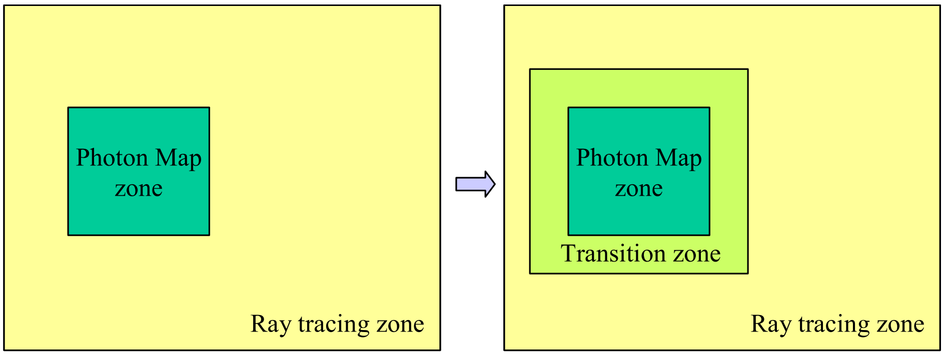

Figure 18: Methodology for the creation of the "transition" zone between the zone of interest (photon maps computation) and the default zone (ray-tracing computation).

Another critical point managed in the new SE-RAY-IR is the overlapping of interest photon map zones. Different approaches have been assessed by OKTAL-SE: choose one zone only, equally take into account the various photons of each zone, compute several evaluation due to each zone and then interpolate estimations, which is the best approach to reduce artefacts of lighting discontinuity.

Besides, an important feature is that the user can define several zones of interest, i.e. identify automatically all the objects included in a bounding volume. This filtering can also be made object by object. For instance, to simulate a car engine diffusion onto the road it moves on, it is possible to store the photons only on the road, without storing any photons reflected on the car itself, in order to spare photons and to focus on the road.

Globally speaking, the SE-WORKBENCH local photon maps implementation is wide opened to parameterisation by the user. Photons can be stored either according to their localisation in 3D scene space, either according to the objects they are mapped on, and the light source they come from.

Beyond this locality optimisation, the fact that the number of samples to use for direct lighting can be enormous was taken into account, and as previously said, that photon maps are not really adapted to very extended light sources. Hence, a stratified sampling technique with multiple reflections was preferred in order to deal with direct and indirect lighting of the sky and the very extended sources (both included in what the so-called environment).

Applying Monte Carlo methods directly gives good results, but is still time consuming. A special cache is used, which enables to compute only a set of necessary points and extrapolate to others.

ENVIRONMENTAL SOURCES

The "environmental sources" are spread sources whose surface is too large to be taken into account by photon mapping. Basically, the sky dome and all the surfaces of the scene the energy of which can be considered as low. For these environmental sources, direct lighting (from the source to the interaction point) and indirect lighting (from the source to the interaction point, but after one or more bouncing reflections), SE-RAY-IR implements a Monte Carlo ray tracing. For a ray intersection with the 3D scene, a bush of rays is traced from the interaction point in order to sample the hemispherical space "seen" by the interaction point. Each ray of this bush is traced through the 3D scene until it is absorbed or reaches the sky dome. As for photon mapping, a "Russian Roulette" algorithm is used to decide if this ray is absorbed, reflected or transmitted.

The primary density of rays in the bush rays is user defined. The evaluation of environment irradiance can be costly, and then an optimisation technique called the "irradiance cache" is used to reduce the number of points where irradiance is evaluated. According to the average distance of the scene surfaces around the estimation point, the cache determines if a sample point has to be computed or if its irradiance can be deducted for the points that have been computed previously and are already in the cache.

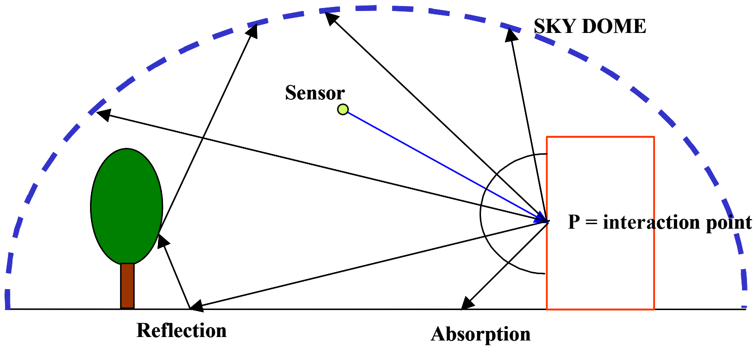

Figure 19: Presentation of the different elements taken into account for the photon maps optimisation. From the “interaction point”, photons are absorbed, reflected and reach the shy dome.

As for photon map, several tests are under development in order to assess the limits of the method.

To give one example, a unitary test has been packaged in order to qualitatively validate the computation of the environment lighting using the SE-WORKBENCH environment rendering method.

This test refers to standard MODTRAN based atmospheric file, including opaque cloud layers so that the sun contribution is zero. The scene contains a horizontal white plane, two small green cubes (one of it not lying on the ground) and one big red cube.

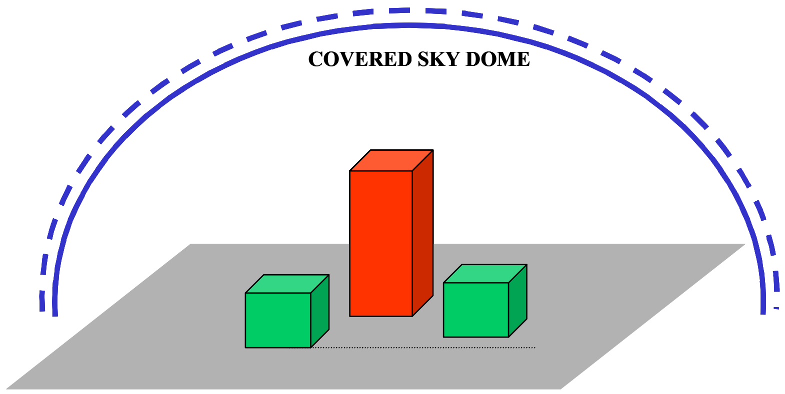

Figure 20: Experimental set-up to test the optimisation method. Note that the right placed green cube is slightly above the ground.

Environment maximum reflection order is set to 10. That is for each evaluation points a set of rays is thrown to evaluate light coming from all directions, and rays are reflected up to 10 times before absorption. Anyway, a majority of rays will be absorbed according to material properties, or will hit the sky before ten reflections. 512 initial rays are used.

The resulting image showing soft shadows under the right green cube and around the others. Visualisation radiance is in range [0, 2.0] W.sr-1.m-2, in the visible spectrum.

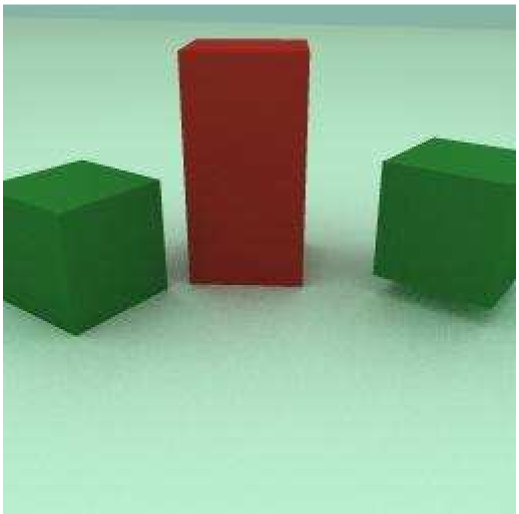

Figure 21: Simulation result using the default method.

This test is then modified in order to validate the use of the irradiance cache for the computation of the environment lighting using the SE-RAY-IR environment rendering method

Environment maximum reflection order is set to 10. That is, for each evaluation points, a set of rays is thrown to evaluate light coming from all directions, then rays are reflected two times before absorption. 512 initial rays are used. Irradiance cache is activated.

The resulting optimizes image is then compared to the reference previous one. As shown in the image difference (without irradiance cache image – with irradiance cache image) the optimised method can be considered as a very good approximation.

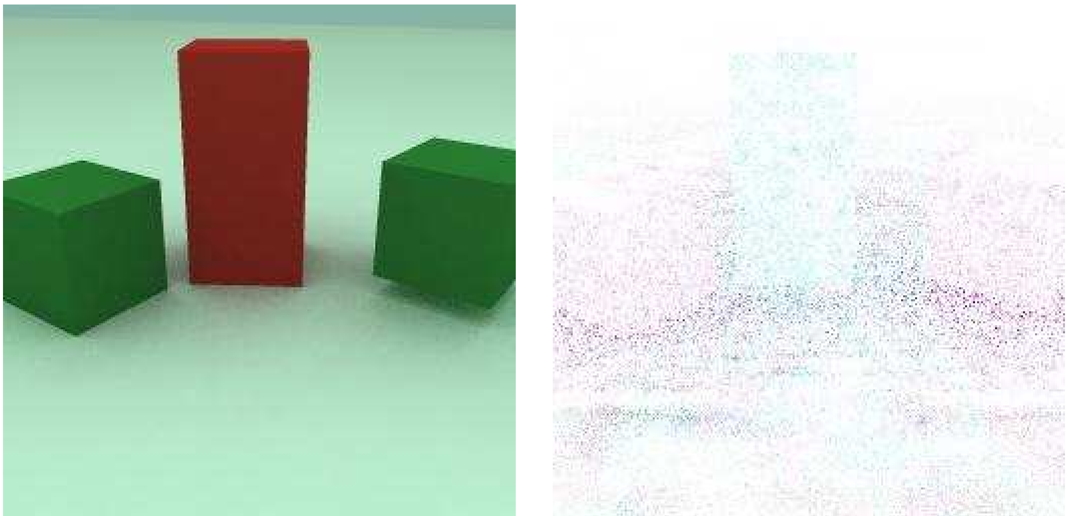

Figure 22: Simulation result using the advanced method with irradiance cache on the left. On the right, the difference image between the default and advanced method is shown. This image difference highlights the impact of the geometrical variation on the optimisation method.

Time measurements and associated benchmark are under development.

8 TECHNICAL SUMMARY

The new version of SE-RAY-IR is merging 4 innovative techniques:

- classical ray tracing (RT)
- photon mapping (PM)
- Monte Carlo distributed ray tracing (DRT)
- Irradiance cache (IC)

Different type of sources are considered:

- Punctual source
- Spread source
- Environmental source
- Sun and Moon

According to the recursion level (primary rays, secondary rays or more), automatically and adaptively, the SE-RAY-IR software automatically selects the best choice for computation.
This choice also takes into account the specular behaviour of the local material.

The following board gives at a glace an idea of this mixing:

SOURCE TYPE	Direct lighting *Diffuse*	Direct lighting *Glossy*	Indirect lighting *Diffuse*	Indirect lighting *Glossy*
Punctual	RT or PM	RT	PM	PM
Spread	DRT or PM	DRT	PM	PM
Environmental	DRT + IC	-	DRT + IC	-
Sun/Moon	RT or PM	RT	PM	PM

9 CONCLUSION

SE-RAY-IR has been stable for years and applied in several applications in the Defence domain. In the frame of infrared spectrum, French DGA/CELAR and BWB/WTD81 (associated to FGAN-FOM) have strongly supported this product.
In 2007, 2008 and 2009, DGA/CELAR and other DGA technical centres, in the frame of CHORALE, the French acronym for SE-WORKBENCH-IR have founded OKTAL-SE to significantly improve the physical realism of SE-RAY-IR rendering and accepted to share these evolutions with SE-WORKBENCH users. One important part of these evolutions concerns photon mapping and Monte Carlo ray tracing add-ons, which has been rapidly presented in this paper.
Lots of algorithms have been implemented, that will be assessed and really used in 2009 by OKTAL-SE in the frame of applications for aircraft IR signature prediction with French DGA, but also by SE-WORKBENCH-IR users themselves.
These evolutions are very important for SE-WORKBENCH-IR future. They are correlative to evolution of demand for real time capabilities with the development of SE-FAST-IR.
First of all, non real time SE-RAY-IR quality is fundamental in order to assess the validity of SE-FAST-IR, the SE-WORKBENCH-IR clone of SE-RAY-IR, based of Open GL graphic board shaders, since SE-FAST-IR is validated by comparison to SE-RAY-IR.
Secondly, thanks to the exponential progress of 3D graphic board HW & SW, many of SE-RAY-IR enhancement can be now implemented on Graphical Process Unit.

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