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Skylight Illumination and Rendering of Urban Scenes

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1 ABSTRACT

A realistic visualization of an urban scene can only be complete, if the aspects of illumination by the skydome as well as the direct visual appearance of the skydome are handled. For the visual appearance, panoramic images of skydomes are standard practice, however skydome illumination for urban scenery based on a realistic model is often neglected due to the large computational cost of the necessary simulation.

We demonstrate a workable solution for generating global illumination approximations for urban scenes. The actual illumination simulation is based on the skydome model by Preetham et al. [1999], which is used in an improved version of the photon map algorithm based on Jensens method [1996]. In order to speed up calculation we use an adaptive acceleration algorithm that calculates lightmaps for all buildings in a scene. By providing a viable solution for including realistic skydome illumination in the real-time visualization of urban scenes, we increase the achievable realism and thereby the acceptance and applicability of global illumination methods in applications such as tourism and planning.

2 INTRODUCTION

Interactive walkthrough applications are rapidly becoming a standard tool in urban visualization. Although these applications provide a significant improvement in the way building data is presented to the user — be it an urban planner or a tourist — the resulting experience is still far from reality. Thus there are a number of aspects of the visualization that do not reflect reality accurately. One of these aspects is illumination. Since urban scenes are normally illuminated by daylight, which is composed of direct sunlight and illumination by the skydome, a realistic simulation of typical illumination scenarios needs to reflect both of these illumination types. By providing illumination for urban scenes, the realism of typical walkthrough applications is sginificantly improved, but additional applications that estimate shadowing or illumination at specific times and seasons can be realized.

Due to these reasons we improved the global illumination algorithms that are part of the Advanced Visualization Engine (AVE) to include skydome illumination, and incorporated a number of necessary speedups for making the simulation possible within fairly short timeframes (on the order of a few hours a the most). The following sections give an overview of our solution.

3 GLOBAL ILLUMINATION

Global Illumination is the general term for using algorithms to simulate and approximate real illumination situations in synthetic scenes. In general, this is used to compute static images with realistic illumination. In order to use the results of global illumination algorithms in the context of urban visualization, it is necessary to make the calculation results available in an interactive viewer. To that end, we decided to store the results of the simulation in so-called „light maps“, illumination textures that are used in a renderer with multi-texturing capability and contain the direction-independet illumination for all objects in the scene.

3.1 Photon Maps

In order to precompute these lightmaps a number of algorithms are feasible, however we decided to use a hybrid approach that is based on the photon map algorithm developed by Jensen [1996, 2001, 2002]. The basic algorithm of the photon map is based on the simulation of the propagation of photons starting at the light sources. Each interaction of a photon with a surface is recorded in a data structure that allows fast searches for nearby hits, e.g. a k-d-tree. Once enough photons have been simulated, illumination at each point in the scene can be approximated by retrieving the closest photon hits at the query point. Using the k-d-tree the n closest hits are retrieved, and due to the resulting distance of the n-th closest photon hit a projected surface area can be computed. Dividing the power of the n closest hits by this projected surface area, results in an estimate for the radiance at the query point.

3.2 Heuristics to avoid Light leaks

Although this algorith works fairly well, it is normally used with a so-called „gathering pass“, that computes the illumination for each pixel in the scene by gathering all illumination affecting the closest object visible in that pixel. This gathering pass is very costly and cannot be efficiently used in conjunction with the generation of lightmaps.

Therefore our hybrid algorithm skips the gathering pass and directly uses the photons stored in the k-d-tree to compute the illumination. This works fairly well for a number of scenes, however the k-d-tree does not store any information about the underlying geometry and can lead to light and shadow-leaks for some types of geometry. In order to overcome these problems we introduced two heuristics that improve the quality of the resulting lightmaps.

The first heuristic computes a better estimate of the area of the n closest photons. This is done by computing the area of these photons using an extended, two-dimensional bounding box of the relevant photons using eight instead of four values to represent the area. Thereby, the covered area is approximated using a generalized octagon, leading to an adequate approximation (see figure 1).

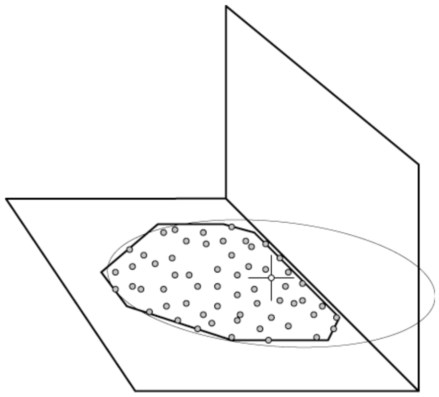

Figure 1: Improved area estimate for computing illumination: the octagon represents a far better approximation than the circle around the query point.

The second heuristic avoids shadow-leaks by casting additional feelers from the query point. These feelers run parallel to the surface and are sent into four or eight equally spaced directions (every 90 degrees or every 45 degrees). By eveluating the extent of free space around the query point in all of these directions, all photons around the query point can be classified if they should actually be used to estimate the illumination. If some photons are outside the region that is covered by the feelers, they are assumed to be behind a wall and discarded from the illumination estimate for this query point (see figure 2).

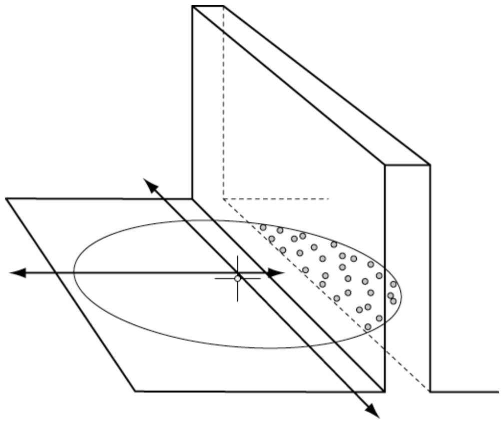

Figure 2: Region feelers are used to discard photons that cannot possible contribute to the illumination at the query point.

3.3 Point light sources

Although point light sources could be handled by the standard photon map algorithm, the speed and quality of the resulting lightmaps could be improved by using direct light source sampling. This is achieved by shooting direct shadow feelers from each lightmap texel to each point light source and thereby calculating whether the corresponding texel is illuminated. By using an adpative version of direct light source sampling, aliasing artefacts in the shadow edges could be avoided.

4 SKYDOME ILLUMINATION

A number of analytical models have been developed to describe sky radiance and its spectral radiance in the context of photorealistic image synthesis; we just give a brief overview over those models.

It should be noted that there exists a significant body of additional work on this topic — such as for instance by Tadamura et al. [1996] or Dobashi et al. [1997] — of which we are well aware, but which we omit in this discussion. These papers also offer valuable insights into the synthesis of absolute skylight radiance values and could equally well have served as base skylight models for our developments.

4.1 Skylight models

For simple sky conditions, the CIE Skylight model [1994] provides satisfying results. An increase in luminance towards the horizon and a bright area around the solar disc can be observed, which result in a quite convincing overall appearance. For higher sun positions this model proves quite useful, however for lower sun positions it lacks the necessary hue variations towards the red part of the spectrum. The model only describes the luminance distribution and a basic color has to be selected, and therefore effects like the red glow of sunset cannot be achieved.

The Perez model [Perez et al., 1993] is similar to the CIE model, but it introduces an additional parameter that accounts for the haze in the atmosphere. The Perez model has been found to be slightly more accurate than the CIE model if its parameters are chosen wisely.

One of the most sophisticated skylight models so far is the one defined by Preetham et al. [1999]. The main improvement offered by their approach is that it provides genuine spectral radiance values for each sample; in this way the varying color hues of natural skies are taken into account. The images produced with this model are very appealing, while the required computational effort is still basically similar to the other models. Due to these advantages we based our skydome illumination on this model.

4.2 Calculating Skylight illumination

The computation of illumination due to a skylight model can be split into two separate tasks: computing direct sunlight illumination and computing the illumination due to the skydome. Direct sunlight can be adequately handeled by approximating the sun with a point light source. The minimal error due to the size of the sun-disk can be neglected in the context of an urban model.

The computation of skydome illumination, however, turns out to be very costly if the standard photon mapping algorithm is used. As this algorithm simulates the photons starting from the light source, it is necessary to target the photons towards the scene. But even with targeting the photons the resulting quality was not satisfying.

For this reason we again used direct light source sampling for the skydome. Thus for each light map texel a number of shaodw feelers are sent towards the skydome, and the radiance of all feelers that are not blocked by geometry is accumulated. Our first approach, using randomly distributed shadow feelers resulted in a high level of noise in the illumination, therefore we switched to quasi-random sampling using a Halton series to compute skydome illumination.

Although the resulting quality was satisfying, the computation time was an order of magnitude to high. This problem was overcome by using a hierarchical sampling approach. First the skydome illumination is computed on a much coarser grid than provided by the lightmap texels, e.g. only one skydome illumination computation for each 16 x 16 lightmap texel. Only if neighbouring computation yield significantly different results, we subdivide and compute the illumination on a finer grid otherwise intermediate pixels are simply interpolated. Only very rapid changes in skydome illumination will lead to computations for each and every light map texel. But since skydome illumination, by ist very nature is varying only very slowly, this hierarchical sampling approach results in impressive speedups.

5 APPLICATION TO URBAN SCENES

In order to demonstrate the presented algorithms for urban scenery, we chose the models provided by the city of Graz. These models are of medium geometric complexity, with most of the visible detail embedded in the textures. This type of model can be generated nearly automatically and can therefore be captured at a moderate cost.

By simulating global illumination in such urban models, a number of new applications for urban models can be realized:

Calculating the impact of shadowing on changes in urban plans: due to the physically based simulation of the illumination a fairly exact estimate of the extent and duration of shadows cast by various buildings can be performed. This can lead to improvements in planning, especially of very large buildings.

The visual impact of new buildings can be more accurately estimated, as their influence on the illumination of nearby buildings can be computed in advance.

The realism of urban walkthrough applications can be increased, thereby increasing their attractivity in e.g. applications for toursim.

6 RESULTS

The following result images show screenshots of an interactive walkthrough of the city of Graz. Figures 3, 4, and 5 show the same scene, rendered with the global illumination information (3), without global illumination information (4), and just the global illumination information without textures (5). Figures 6, 7, and 8 show different screenshots, demonstrating sharp shadows cast from the sun that is handled as point light source (6), the effect of sun and skydome illumination on an urban plaza (7), and the skydome gradient around the sun (8). The illumination in this visualization was precomputed in less than an hour using the described algorithms. The resulting lightmaps were rendered using the multi-texture feature of the Advanced Visualization Engine (AVE) (www.vrvis.at/rendering/research/ave) developed at the VRVis Research Center (www.vrvis.at).

Figure 3: Screenshot from an interactive walkthrough with precomputed illumination and skydome.

Figure 4: The same scene as figure 3, without global illumination calculation.

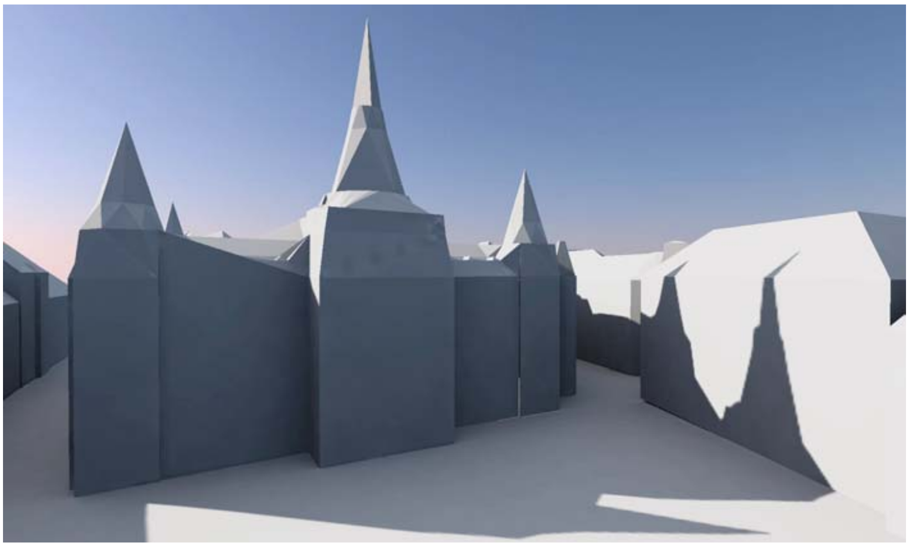

Figure 5: The light maps containing the global illumination information that was used in figure 3.

Figure 6: Sharp shadows cast from the sun, which is handled as point light source.

Figure 7: The effect of sun and skydome illumination on an urban plaza.

Figure 8: The skydome gradient around the sun.

7 CONCLUSION AND FUTURE WORK

We demonstrated the feasibility of applying global illumination algorithms to urban scenery. A number of improvements to standard algorihms were combined to achieve these results, providing a significant speedup in the illumination computation. The resulting interactive visualization shows a significantly higher degree of realism.

The current algorithm is adequate for medium sized urban scenes, containing a few tens of blocks of houses. For these types of scenes the precomputation of the illumination can be performed overnight. For larger scenes additional improvements will be necessary to make global illumination possible: Oftentimes in urban scenes, the same form or type of building is repeated, thus the actual geometric configuration for skydome illumination is very similar. In this case, the lightmap computation need not be repeated, but can be reused multiple times. Although we do not have a general method for automatically determining, if an illumination context is similar to a previously computed one, the effectivenes of this approach is obvious for large areas of repeating building structures.

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