Computer Aided Lighting for architects and designers

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1. Introduction

Designing lightings in a 3D-scene is a general complex task for building conception as it is submitted to many constraints such as aesthetics or ergonomics. This is often achieved by experimental trials until reaching an acceptable result.

Several rendering softwares (such as Radiance [Ward 94]) allow an accurate computation of lighting for each point in a scene, but this is a long process and any modification requires the whole scene to be rendered again to get the result. The first guess is empirical, provided by experience of the operator and rarely submitted to scientific considerations. Our aim is to provide a tool for helping designers to achieve this work in the scope of global illumination.

We consider the problem when some data are asked for : on one hand the mean lighting in some zones (for example on a desktop) and on the other hand some qualitative information about location of sources (spotlights on the ceiling, halogens on north wall,...). The system we are conceiving computes the number of light sources, their position and intensities, in order to obtain the lighting effects defined by the user. The algorithms that we use bind together radiosity computations with resolution of a system of constraints.

2. Inverse lighting: previous works

Several works have been achieved to help the user who is searching the best lighting in a three-dimensional scene, these techniques are called "inverse lighting methods".

The first works only allowed to determine the direction of a light source from an highlight on a surface. Van Wijk [Wijk et al.85] proposed to the user to point out a pixel on an image representing the three-dimensional scene. A ray is then traced throughout this pixel to determine the corresponding point on the surface of the model. For this point, the surface normal is computed and the light source direction is obtained through the mirror direction. The light source is added along this direction. The aim of his works was to allow the user to position easily highlights in three-dimensional models. Hanrahan [Hanrahan et al.90], in his texture editor, allows the user to position a highlight on a simple primitive, i.e. a sphere. The computation of the direction of the light source is done simply along the mirror direction in comparison with the surface normal. Then, the light source direction is applied to the three-dimensional model.

Later, Poulin [Poulin et al.92] presented a method based on the use of the highlights and the shadow volumes to define the geometry, the direction and the position of a light source. The point of the highlight which has the maximum intensity is used to define the direction, as in Van Wijk and Hanrahan ; but with the highlight information he extracts also the roughness coefficient which is in relation with the highlight size. The shadow volumes are used to define the light source direction and position. Poulin permits to define the shape of extended light sources (linear or polygonal) which are represented with a set of point light sources disposed at their vertices. However, his approach concerns only the light directly issued from light sources (or direct light) ; furthermore the intensity and color of the light source can't be determined intuitively by the user.

Schoeneman [Schoeneman et al.93], as well as Kawai [Kawai et al.93], determined the light sources intensities, knowing the number and the position of light sources, in a three-dimensional scene for which the geometry is fixed. Schoeneman's method consists to paint directly in a three-dimensional model a certain number of lambertian surfaces for which the reflectances are fixed, i.e. to fix the desired color in a target image and to retrieve the intensity of each light source. Kawai, in the case of classical radiosity, determined the intensities of all light sources and the elements reflectivities to create a room for which the user will have a feeling of comfort, or to minimize the overall energy.

All these methods which decrease the number of cycles needed for the creation of an image, by defining certain causes from effects, are limited to a particular aspect of the inverse lighting problem, as we have shown. None of these approaches allow the user to determine intuitively the positions and intensities of the light sources, and the number of sources at once. Our approach aims to define all these parameters.

3. Presentation of the method

We are in the scope of classical radiosity [Sillion 93], i.e. a discretized scene with n lambertian facets and a linear model Mb=e, where b is the vector of unknown radiosities and e that of light emittances.

The facets are splitted into three groups :

- n1 facets which are *a priori* possible sources
- n2 facets passive and unknown
- n3 facets passive and known

Radiosities and light emittances are indexed by a value of 1,2 or 3 according to their group, leading to the system :

$$\begin{pmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{pmatrix} \begin{pmatrix} b1 \\ b2 \\ b3 \end{pmatrix} = \begin{pmatrix} e1 \\ 0 \\ 0 \end{pmatrix}$$

There are n equations and 2n1+n2 unknowns : e1,b1,b2 (e1 and b1 are separated, despite the fact that in practical cases their difference is small and e1 is only the interesting unknown).

After re-ordering the equations we obtain a system which is under or over-constrained, depending on the values of n1,n2,n3 :

$$\begin{pmatrix} I & -M_{11} & -M_{12} \\ 0 & -M_{21} & -M_{22} \\ 0 & -M_{31} & -M_{32} \end{pmatrix} \begin{pmatrix} e1 \\ b1 \\ b2 \end{pmatrix} = \begin{pmatrix} M_{13}b3 \\ M_{23}b3 \\ M_{33}b3 \end{pmatrix}$$

To solve it in this general case we use a pseudo-inversion based on Singular Value Decomposition (SVD) [Golub 83][Nashed 76], which is numerically a good choice for robustness, stability, performance, and allows a precise control over degenerate cases when matrices are ill-conditioned. In a first step we have considered only the over-constrained case, because it is simpler and otherwise the unknown degrees of freedom would be estimated by external considerations.

The physical validity of the results is tested: unacceptable values must be filtered, because the physical coherence of the solution is not guaranted (which is the case for radiosity solution, due to the construction of the matrix) and also because values out of range can come from situations when facets have very different areas.

Later, a new resolution of the complete radiosity model can give a more precise computation based on these estimated sources.

4. Results

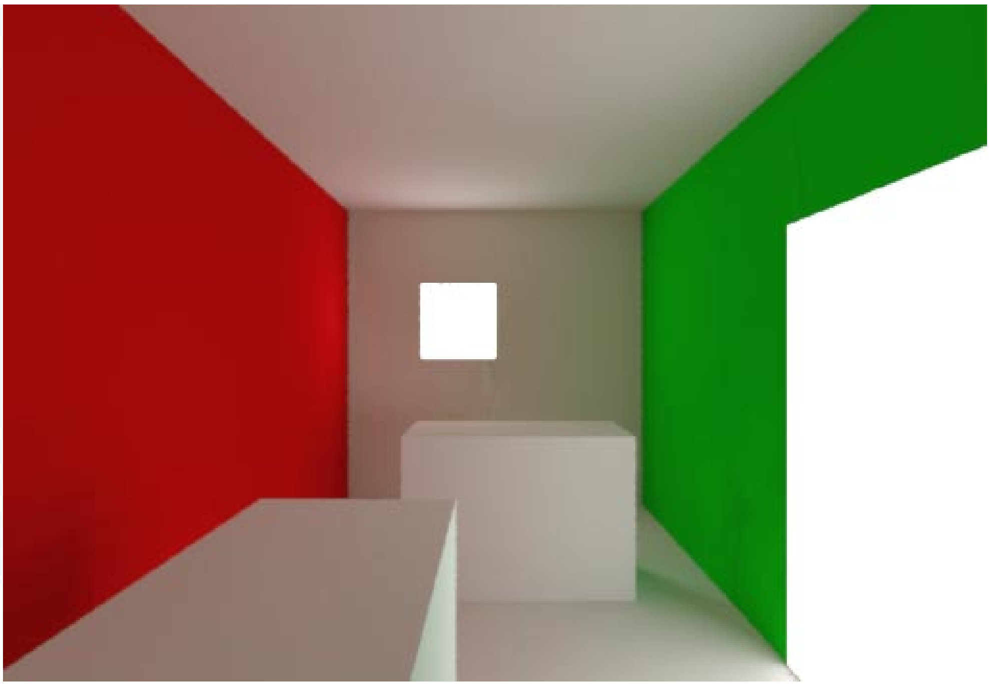
As a first prototype we have done tests with a two-dimensional radiosity model written under Maple to validate the method. For current developments we use as a basis the radiosity package Rad by S.Pattanaik [Pattanaik 93], which is compatible with Radiance at scene description level. We have implemented computations of e1, b1, b2, given b3, for simple significative scenes.

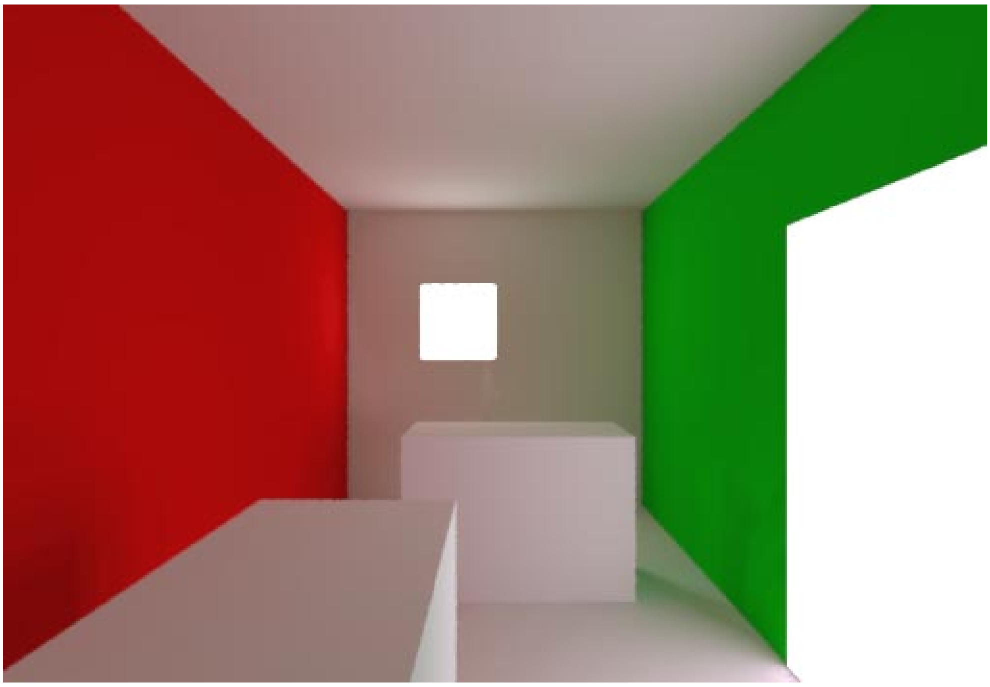
Picture 1 shows the scene used to test our algorithm rendered with Radiance. It is composed of 228 facets and comprises two light sources located on different walls. The bright colors of the walls are used to illustrate color bleeding. The scene was first rendered with Rad to obtain an intensity file containing the resulting intensities of all facets.

In a second step, a modified version of the scene was passed to the inverse lighting process. In this scene all the informations concerning the light sources were suppressed, and the facets of both far end and green walls were classified as being of type n1, indicating that they could be possible light sources. We assigned to all other facets of the scene their corresponding values found in the intensity file previously produced by Rad. The filtering of possible facets is done by dropping values under some empirical threshold. Then the system indicates which of the n1 type facets were found to be light sources, and for each produced the intensity value.

Picture 2, rendered with Radiance, shows the initial scene, in which the light sources were replaced by those found by the inverse lighting system. As we can see both images are very close to each other. Notice that the number and position of the light sources which have been found are the same as in the initial scene, and the emittances of sources are almost identical.

So, our system is able to compute, for a given scene with fixed intensity values on certain points, the number of light sources, their position and intensities in the over-constrained case, in order to obtain the lighting effects defined by the user.


Picture 1: initial scene.


Picture 2: resulting scene.

5. Questions and further developments

At this stage few problems remain open and are subjects of future work :

- Meshing level: facets can be subdivided or groupped, modifying both the system to solve and the values of n1, n2, n3 leading to simultaneous usage of refined subdivision to choose rapid and rough solutions or more precise ones but with heavier computations.

- Process of validation: it must be created to decide if the positions and/or emittances are in agreement with the conditions demanded by the operator. For the moment we compare the light sources intensities found by our system with those of the test scene. It is necessary to have a set of quantitative criteria validating the obtained results, independantly of the operator, for example using a distance between the required scene and the computed scene [Rushmeier et al.95], instead of a subjective appreciation of the operator.

- Extraction of real sources: i.e. from a set of lighted facets, after an improved filtering, an adjustment has to be done by finite combinations of predefined sources, taken in a list of possible geometries and known types of light sources.

- General solution of least squares problem: SVD computes minimal norm solution but it is unlikely convenient. Thus two extensions are possible, one with complete solution in case of an under-constrained system (more helpful for the user), the other with a more general metric involving weighted facets (depending on size, reflectance and practical importance).

- Filtering by singular values: SVD is optimal in the sense of best decomposition in sum of outer products ; so, for large size models we can replace the full matrix to solve by an approximation resulting from dropping non-significative SV.

- Generalization to other types of situations : practical cases need to take in account directional sources and more complex types of emitters, which are not well treated by strictly lambertian radiosity.

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