Spectral Radiosity Rendering Application for Lighting Researches

Ádám Tilinger, Gábor Madár

tilinger.adam@rkk.bmf.hu

Abstract: Lighting research often requires human surveys for defining subjective qualities. Creating new settings, new test scenarios is usually a time and resource-consuming task. As today many preference and comparison investigations are carried out on computer displays, the pictures to classify might well be generated. The aim of my current work is to create a rendering application that can model light appropriate enough to be used in lighting researches.

Keywords: radiosity, lighting, spectral radiant exitance

1 Radiosity

There are many rendering algorithms to simulate a real, shaded 3D environment on a computer screen. Most of these however apply strict limitations such as the limiting the number of repercussion of rays, photons or taking in account those of special angle. Though there are methods to compensate the errors caused by these limitations, these are usually just cosmetical improvements, making the resulting images even less appropriate for accurate lighting researches.
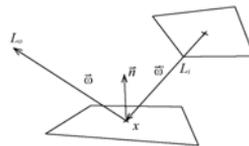
$$L_o(x, \vec{w}) = L_e(x, \vec{w}) + \int_\Omega f_r(x, \vec{w}', \vec{w}) L_i(x, \vec{w}')(\vec{w}' \cdot \vec{n}) d\vec{w}'$$

Figure 1
Shading equation

However, there are global illumination algorithms which handle light physically appropriate. These methods aspire to solve – applying inversion, iteration or expansion – the shading equation (Figure 1) without disregarding the full caustic

part. This equation is an accurate model of light-surface interaction and serves as a basic integral equation for all rendering algorithms. One of the most well known methods solving it without simplification is called radiosity.

1.1   Theory

The approach was originally used for thermal engineering purposes, radiative heat-transfer theory. In the mid eighties the method was introduced to photorealistic image generation indepently by Goral et al. and Nishita and Nakamae although the credit for the first images rendered by the algorithm must go to Moon and Spencer.

Considering mathematics of the method, it is a finite-element inversion solution of the shading equation. It reduces the space to elemental surface patches, thus simplifying the integral equation into simultaneous linear equations. Technically these equations distribute the original radiant flux of the light sources on the patches.

Algorithmically the method can be divided into two main phases. The first one covers the determination of the quotients of the linear equations, called form factors. These quotients are computed from the geometry of the scene applying double surface integrals.

The second part of the algorithm is to solve the radiosity equations for all nominated wavelengths. This can be done by Gaussian elimination (slow and numerically instable) or by iteration (like Jacobi-, Gauss-Siedel- or Southwell-iteration). However, the generation of the form factor matrix ensures that the matrix of the radiosity equation is invertible, thus it can also be solved by matrix inversion. By solving the set of these equations we obtain the radiant exitance, radiance and ultimately the luminance of each elementary patch.

1.2   Limitations

Although radiosity models light accurately, there are some restrictions on the environment. The main limitation of the algorithm is that it handles Lambertian surfaces. These are ideal diffuse surfaces with a constant radiance or luminance that is independent of the viewing direction. This means no specular reflections can be rendered, though it also permits to display the resulting scene via an incremental rendering system after solving the radiosity equation. This enables the real time exploration of the environment.

An obvious limitation is the discretisation by tesselation. Each patch, surface element has a uniform exitance and irradiance distribution. As a result, the scene must have immense number of patches to render continuous transitions that eventuates lengthy computation time. A theoretically inaccurate but widely used

solution is the application of incremental shading methods like Gouraud shading while displaying the rendered scene.

There are also some other restrictions on the environment, like no transmissive materials can be simulated, that the intervening medium is nonparticipating, or that the algorithm cannot solve the interaction of the different wavelength samples (like UV luminescence).

We have to point out that none of these assumptions represent fundamental constraints for the theory, they make solving the equation a tractable problem for computers.

2   The Application

Although radiosity rendering applications are quite numerous, up to now – to the authors' knowledge – none of them allow to define materials with spectral reflectance distribution. Most of these are developed for computer graphics, imagery instead of lighting research thus the common three channels are used. This prevents researchers from applying them in appropriate light simulation, investigations based on computer generated images. Our goal was to develop software especially for this purpose. To make it a viable tool for adequate researches we had to put special emphasis on computational accuracy. Thus we had to find the most precise algorithms for the two phases of the radiosity approach.

The software is supplied with a MEL exporter script, which enables to export scenes from Autodesk Maya modelling package. This permits easy environment building (provided knowledge of and access to the Maya).

Figure 2
Flat shaded radiosity rendering of "Scene C (Office)" by the application

The application is able to display the final radiosity rendered scene with flat shaded (for precise but uniform patches) and Gouraud shaded (for smooth transitions) method and can be explored in real time. These are obviously displayed on the limited colour gamut of a monitor display, but spectral data is also stored. The software is fitted up with a wireframe and unshaded flat (colours derived from reflectances only, no geometry) display mode too for debugging reasons.

2.1 Generating the Form-Factor Matrix

To generate the radiosity equation the first task is to calculate the form-factor matrix. This can be done by a number of methods each different in its computational accuracy and time requirement. The following algorithms are implemented in the application:

2.1.1 Simple Method

A quick approach, disregarding all geometrical data except the actual patch sizes, angles between patch normals and patch distances. This results prompt form-factors for rapid imagery not suitable for lighting research concerns. Nevertheless it has it raison d'ętre for swift testing of the scene.

2.1.2 Hemisphere, Quasi-Hemisphere Method

This method projects one patch on a hemisphere over the other and calculates the form-factors based on the surface size of this projection. Exact projections onto the hemisphere are hard to implement (analytical solutions boost run-time greatly), thus these methods usually apply some kind of estimations (discretizing the hemisphere or simply reducing the projection into a polygon). However that may be this approach still is a simplification, it disregards the form of the patch on which the hemisphere is built. This method provides images of different usability according to the estimation used with reasonable run-time.

2.1.3 Analytical Solutions (Monte-Carlo Sampling, Numerical Integration)

The most precise solution is to solve the double surface integrals. There are numerically imlementable methods for this reason. The Monte-Carlo sampling approach employs random samples to compute the results. It is also possible to reduce the surface integrals analytically to curvilinear integrals which could be solved numerically. These approaches yield accurate results, though their time requirement is rather large. For lighting research purposes we recommend these solutions.

2.2   Solving the Radiosity Equation

To solve the radiosity equation a Matlab program is applied based on matrix inversion. Due to the huge size of the matrix of the linear equation it is subdivided into smaller matrices and the final output. Though this approach implies a great number of operations which usually tends to generate calculational errors, the evaluation of the software showed that these remain in a acceptable range.

2.3   Evaluation

To verify the accuracy of the application the results of the software were first tested against the sample settings of diffuse, Lambertian materials defined by CIE. Though these only specify simple layouts and a restricted set of measured illuminances it served as an effective evaluation. The curve fitted on the given sample points matched the monochromatic illuminances generated by the application (with analytically derived form-factor matrices).

To test special layouts, complex environments, the software was compared to DiaLux, a commercially accessible lighting simulation software. The results show high correlation.
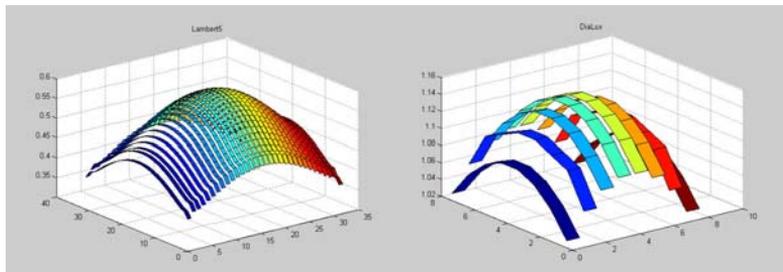

Figure 3
Monochromatic illuminance distributions on a floor rendered by our application and DiaLux

Comparison of results to measurements of real life scenes is the final step of the evaluation. Up until now the development lacks this phase of the evaluation, reference settings are being collected.

2.4   Limitations and Future Objectives

Besides the limitations of the approach mentioned previously, the application of the software in lighting research suffers from additional obvious limitation namely the monitor colour gamut. Although the result of the rendering equations is spectral data of desired sampling rate, computer monitors are not able to display all of these correctly. Thus some colours must be projected on the gamut resulting

fake colours. This cannot be helped, although this is not a limitation of the application instead of lighting investigations based on images displayed on computer screens.

Another limitation is the Lambertian nature of light sources. This would reduce the usability to indoor settings, though – with an initialisational step – directional or arbitrary light sources can also be simulated.
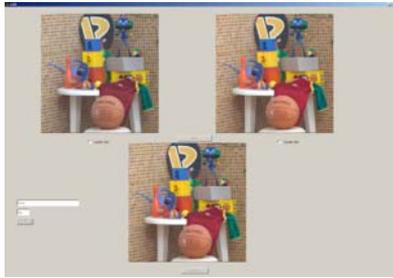

Figure 4
Screenshot of a comparison test application (courtesy of Gábor Madár)

Our future plan is to utilize the application in specific comparison and preference investigations previously concluded with measured data and compare the results of the two.

Conclusions

As a conclusion of this work we can state that radiosity is an apt tool for generating optically appropriate images feasible for lighting research purposes.

References

[1]   Ashdown I.: Radiosity: A Programmer's Perspective, 1994

[2]   Baum D. R., Rushmeier H. E., Winget J. M.: Improving Radiosity Solutions Through the Use of Analytically Determined Form-Factors, in Computer Graphics, Volume 23, Number 3, July 1989, pp. 325-334

[3]   CIE 171:2006 Test Cases to Assess the Accuracy of Lighting Computer Programs

[4]   Goral C. M., Torrance K. E. Greenberg D. P., Battaile B. T.: Modeling the Interaction of Light between Diffuse Surfaces, in Computer Graphics 18(3), (ACM SIGGRAPH '84 Proc.), 1984, pp. 213-222

[5]   Moon P., Spencer D. E.: Lighting Design by the Interflection Method, in Journal of the Franklin Institute 242, 1946, p. 465

[6]   Nishita T., Nakamae E.: Continuous Tone Representation of Three-Dimensional Objects Taking Account of Shadows and Interreflection, in Computer Graphics 19(3) , (ACM SIGGRAPH '85 Proc.), 1985, pp. 23-30