An ambient light illumination model.

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Abstract. In this paper we introduce an empirical ambient light illumination model. The purpose of the development of this model is to account for the ambient light in a more accurate way than it is done in Phong illumination model, but without recoursing to such expensive methods as radiosity. In our model we simulate the indirect diffuse illumination coming from the surfaces of the scene by direct illumination coming from the distributed pseudo-light source. The estimation of indirect illumination is based on the concept of obscurance coefficients that resemble the integrated weighted form-factors computed for some vicinity of a given point. The same idea is used to account illumination of a given point (patch) from light sources. This illumination is computed as a sum of direct illumination calculated using the standard local reflection model and empirically estimated indirect illumination based on the same obscurance concept.

Keywords: illumination model, ambient light, radiosity, form-factor, obscurance.

1. Introduction

The principal goal of realistic image synthesis is to develop the methods that would allow to visualize three-dimensional scenes realistically. To achieve this goal a number of illumination models have been elaborated. These models range from local illumination models that are easy to implement and fast to compute to much more complex global methods that allow the generation of photorealistic-quality images [Watt92, Foley92]. The latter methods range from classic schemes [Goral84, Whitt80] to more modern approaches [Hanr91, Cohen93, Sill94, Sbert93, Sbert96]. The other way to create realistic images is based on the use of more ad hoc techniques (e.g., procedural shaders in MentalRay® or RenderMan® [Upst92]) that strive to recreate the most appealing lighting effects and may sacrifice the physical realism for this goal.

In this paper we introduce an empirical ambient light illumination model. Our model simulates the indirect diffuse illumination coming from the surfaces of the scene by direct illumination coming from the distributed pseudo-light source. The use of this model enables to account for ambient light without recoursing to the expensive radiosity method. Due to the nature of indirect illumination simulation, it is possible to reproduce appealing and realistic images without explicit light source setting at all. This feature enables us to quickly preview the scenes that look appealing and realistic.

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The idea of the method lies in computing the *obscurance* of a given point. Obscurance is a geometric property that reflects how much a given surface point is open. For a given scene, obscurances for each patch can be computed only once and stored into file. This will enable to quickly recompute the lighting in the environment with moving light sources.

The computation of obscurances involves form-factor determination in the vicinity of a given point. Due to the locality of the method, it is much faster than radiosity, while the generated images are realistic and look similar to the ones generated by radiosity after a number of iterations.

The same idea is used to account illumination of a given point (patch) from light sources. This illumination is computed as a sum of direct illumination calculated using the standard local reflection model and empirically estimated indirect illumination based on the same obscurance concept.

2. Observations leading to the obscurance illumination model.

Most local illumination models use ambient light to account for secondary diffuse reflections in the environment. These models usually assume that ambient light is constant over the whole scene. Clearly, this is just a rough approximation. E.g., in a room lit with the diffuse light the illumination over the surface of the walls is not constant – it is normally darker near the room corners. A similar effect is a shadow under the car standing on the snow in a cloudy day. These lighting (darkening) effects in the obscured areas can be modeled with the use and at the expense of radiosity method, since this global illumination model takes into account secondary diffuse reflections.

Our goal is to develop an illumination model that would enable us to reproduce the darkening effects in the obscured areas by empirically accounting for indirect illumination without recoursing to the expensive radiosity solution. We simulate indirect illumination by a direct illumination of a specific distributed ambient light source. The darkening in the obscured areas is achieved by measuring the geometric obscurance in these areas.

The rest of this paper is organized as follows. We start with the 'practical' explanation of our illumination model, showing how it works and how to compute the illumination using it. Then we give some physical foundations of the model. Finally, we show some results.

3. Obscurance illumination model.

As it was stated above, our illumination model is based on a more accurate empiric accounting for the indirect illumination than it is done for ambient light in Phong illumination model and does not involve expensive computations like the ones in radiosity. Similarly to radiosity, our model is view independent and is based on subdividing the environment into discrete patches.

Our primary observation is that in the environments illuminated by diffuse light it is usually darker in obscured areas. Our illumination model is based on the notion of *obscurance*. Roughly speaking, *obscurance* measures the part of the hemisphere obscured by the neighbor patches. E.g., near a corner of a room the obscurance of patches is higher than on the plane open parts. From the physics of light transport point of view, obscurance simulates the lack of secondary light ray reflections coming to the specific parts of the environment that makes them darker. This is unlike radiosity where secondary reflections add the intensity.

3.1. Obscurance illumination model without light sources.

Let's assume firstly that there are no specific light sources in the environment, in other words, the environment is lit by a perfectly diffuse light coming from everywhere. We will better elaborate this notion in the following sections.

Definition. Let P be a point on the surface in the scene, x belongs to the unit hemisphere hS^2 centered in P, aligned with the surface normal in P and lying in the outer part of the surface. The function $L(P,x)$ is defined as follows:

$$L(P,x) = \begin{cases} dist(P,C), \text{where C is the first intersection point of ray Px with the scene} \\ +\infty, \text{otherwise (ray Px does not intersect the scene)} \end{cases} \quad (1)$$

Note, that for properly constructed scenes any ray outcoming from the point P on a surface always hits a frontface before a backface.

We assume that the more patch is open, the more its intensity is. In other words, the farther the intersection point is in a given direction, the more energy is coming from this direction to the patch. Therefore the intensity of a given patch can be approximated as follows:

$$I(P) = \frac{2}{\pi} \times I_A \times \iint_{x \in hS^2} \rho(L(P,x)) \cos \alpha dx, \quad (2)$$

where:

$\rho(L(P, x))$	–	an empirical mapping function that maps the distance $L(P, x)$ to the first obscuring patch in a given direction to the energy coming from this direction to patch P
α	–	the angle between the direction x and patch normal
I_A	–	ambient light power - a global constant for the whole environment

Let's discuss the meaning of the mapping function $\rho()$. Firstly, this function is a monotone increasing function of L. Indeed, we assume the farther the patch is obscured in a given direction, the more light is coming from it. Secondly, this function is up bounded. This reflects the observation that normally the lighting of a given point is primarily affected by its neighborhood. This is especially true for the environments without bright light sources that may affect the illumination at large distances. Therefore, we conclude that the function $\rho()$ has the shape shown schematically on Figure 1. The function $\rho(L) = 1$ for $L > L_{max}$. The shape and the meaning of the mapping function $\rho()$ is discussed more formally in the following sections.

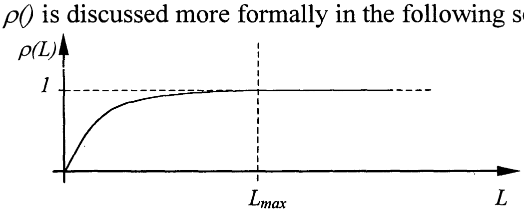

Figure 1. An example plot of a typical function $\rho(L)$

Since $\rho(L) = 1$ for $L > L_{max}$, we can take into account only the intersections within some neighborhood of a given point – if the ray Px does not intersect any patch at the distance less than L_{max}, it may be assumed that it does not intersect any patch at all and the energy coming from this direction is constant.

Definition. Let P be a point on the surface in the scene. *Obscurance*[1] of a point P is defined as follows:

$$w(P) = \frac{2}{\pi} \times \iint_{x \in hS^2} \rho(L(P,x)) \cos\alpha dx \,. \tag{3}$$

So defined, the obscurance is the weighted average length of a chord originating from the point P (the length of chords is measured between P and the first intersection with a patch in the scene). Clearly, for any surface point P: $0 \le w(P) \le 1$. E.g., for a point standing in the middle of the base of a large hemisphere $w(P) = 1$. The function $w(P)$ reflects the local geometric properties of point P. Obscurance value 1 means that the patch is fully open, 0 - fully closed (this may happen only in the degenerate cases). Typical obscurance values for different patches are illustrated on Figure 2. As follows from its definition, patch obscurance resembles patch's average form-factor (see Section 5).

From the equations (2) and (3) we conclude that the intensity in point P can be computed as follows:

$$I(P) = I_A * w(P). \tag{4}$$

The equation (4) actually determines the illumination model working in the absence of light sources. This model can be called *locally-global* since it enables to directly compute the intensity for a given patch, but the computation involves the analysis of the local environment geometry.

On Figure 2 we show a snapshot of a real scene the illumination for which is computed using equation (4) (there are no specific light sources). Notice that a number of pseudo-shadow effects are clearly visible. We claim that the scene looks similar to the view in a cloudy day.

The use of obscurances facilitates helps to outline the surface profile without light source setting at all. Indeed, in practice the task of light source position selection is fairly delicate and laborious, since it requires a number of iterations to produce appealing results (that is the goal in many applications, e.g. in video games). So the purpose of actual illumination calculation is to show shadows and color light spots.

Obscurance is an intrinsically geometric property - it does not depend on light sources, so for a given scene it can be computed only once and stored for future use to recompute the lighting from the moving light sources, or while stuffing the light sources during the environment editing.

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[1] The name 'obscurance' is a bit confusing, since it actually denotes the 'openness' of a patch, but we prefer to stick to the earlier introduced name [Zhuko98].

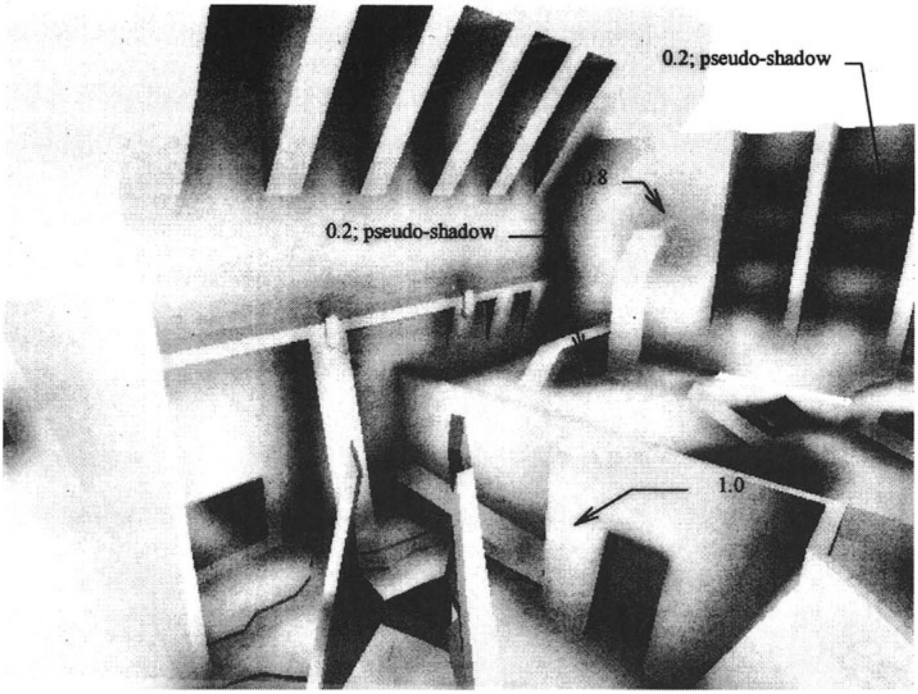

Figure 2. Obscurances of different patches.

An empiric approach called 'accessibility shading' resembling the use of obscurances was exploited in [Mill94], where similar geometric properties of the surfaces were used to recreate specific visual effects such as aging of materials.

3.2. Obscurance illumination model accounting for light sources.

The goal of our illumination model is to account indirect illumination in an easy manner. To compute the illumination of a given patch caused by a given light source, we separate the illumination to the direct and indirect terms. We compute the direct illumination using the standard local diffuse illumination model. The indirect illumination from the light sources is empirically accounted (weighted) with the help of obscurance coefficient as well. Specifically, we use the following equation (the extension of the equation (4)):

$$I(P) = (I_A + I_S) * w(P) + I_S, \qquad (5)$$

where:

I_A - ambient light intensity

I_S - the sum of direct intensities coming from visible light sources,

$$I_S = \sum_{j=1}^{N} \delta(j) \frac{I_j}{r_j^2} \cos\alpha_j, \qquad (6)$$

where:

N - the number of light sources in the environment

I_j - the intensity of *j-th* light source

r_j - the distance from light source j to patch P
α_j - the angle between direction toward the j-th light source and patch normal
$\delta(j)$ - 1 - if j-th light source is visible from patch P, 0 - otherwise

On Figure 3 we show a fragment of the same scene rendered using the equation (5) (with a number of light sources added). Notice that a number of shadows and light spots appeared, but the overall impression does not differ much from the scene rendered with obscurances only.

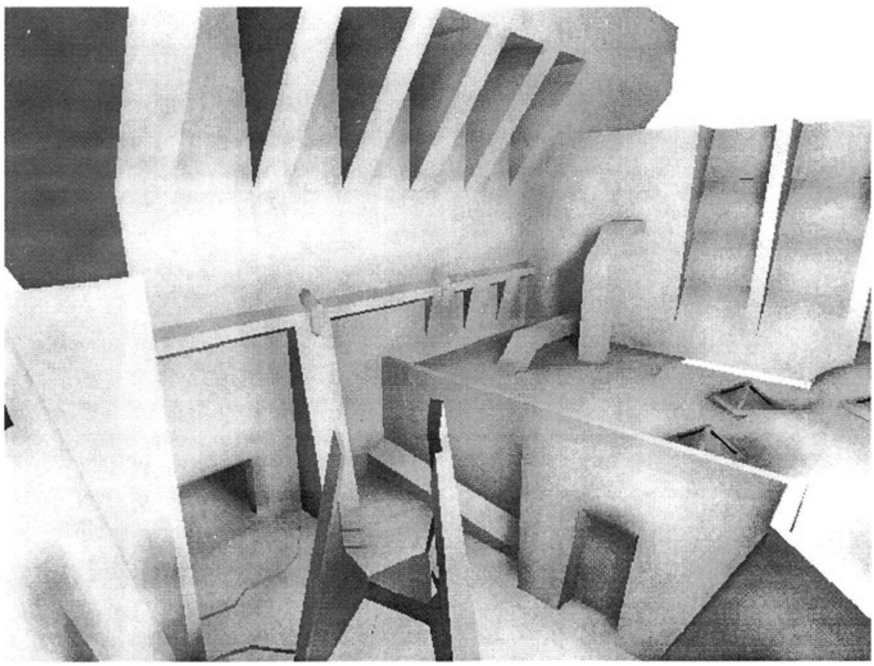

Figure 3. The same scene rendered using the equation (5).

4. Physical justification of the model.

We start the justification of our model by first considering the environment illuminated by purely diffuse light without specific light sources. In our model, to simulate the diffuse light we assume that the environment is filled with the emitting non-absorbing gas with constant emittance λ per unit volume. Indirect illumination from the surfaces is modeled using direct illumination coming from this gas. Clearly, the more the visible gas volume is from a given patch A, the more this patch is illuminated.

It is well known that the perceived intensity (brightness Y) is usually estimated as a gamma-corrected value of the actual intensity [Poynt93]:

$$Y = (I)^{1/\gamma}, \text{ where } \gamma \approx 2.2 \dots 2.5 \qquad (7)$$

Let's compute now the actual illumination of the patch P formally. The differential intensity $I_{P,\,dV}$ coming from a volume element dV to patch P is equal to (Figure 4):

$$I_{P,\,dV} = \lambda \frac{1}{4\pi r^2} \cos\alpha dV\,, \tag{8}$$

where:

α - is the angle between patch normal and the direction toward the volume element

r - the distance between the patch and volume element.

In equations (2) and (3), x was a surface element of a unit hemisphere hS^2; $dx = sin\varphi\, d\varphi\, d\psi$. Computing the intensity of patch P due to direct illumination of the gas and taking into account that $dV = r^2 sin\varphi\, d\varphi\, d\psi\, dr$ in polar coordinates, obtain:

$$I = \lambda \iiint\limits_{over\,visible\,volume} \frac{1}{4\pi r^2}\cos\alpha dV = \lambda \int\limits_0^{2\pi} d\psi \int\limits_0^{\frac{\pi}{2}} d\varphi \int\limits_0^{L(\varphi,\psi)} dr \frac{1}{4\pi r^2} r^2 \cos(\frac{\pi}{2} - \varphi)\sin\varphi =$$

$$= \frac{\lambda}{4\pi} \int\limits_0^{2\pi} d\psi \int\limits_0^{\frac{\pi}{2}} d\varphi L(\varphi,\psi)\sin^2\varphi = \frac{\lambda}{4\pi} \iint\limits_{x\in hS^2} L(x)\cos\alpha dx \tag{9}$$

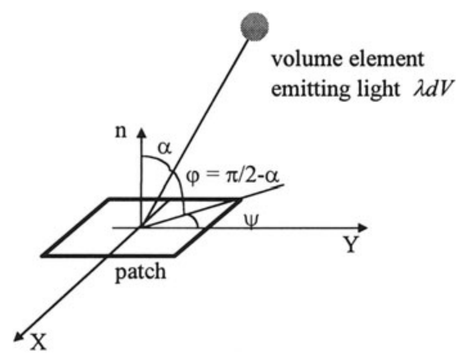

Figure 4. Illumination of a patch by a gas volume element

Note, that equation (9) is similar to equation (2). The difference is that in the equation (9) the distance $L(x)$ is not weighted by a function $\rho(L)$. In (9) the expression $I(P,x) = \frac{\lambda}{4\pi} L(x)\cos\alpha dx$ shows the differential intensity coming from the given direction x. Due to the equation (7), unlike $I(P,x)$ the perceived intensity $Y(P,x)$ is non-linearly dependent on L. The more the distance L, the less is the relative influence of the newly accounted volume elements to the perceived intensity. On Figure 5 schematic plots of $I(P,x)$ and $Y(P,x)$ as a function of distance L are shown.

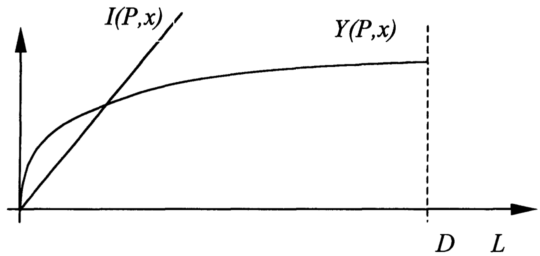

Figure 5. A schematic plot of the dependence of I(P,x) and Y(P,x) of L. D is the diameter of the environment.

In practice, we approximate the dependence of *Y(P,x)* of the distance *L* by the function $\rho(L)$ plotted schematically on Figure 6.

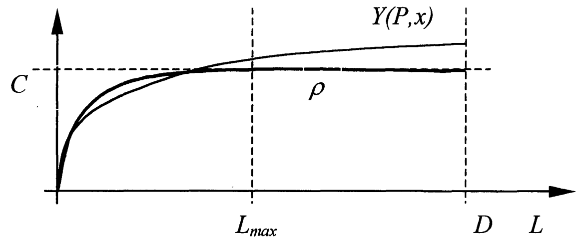

Figure 6. A schematic plot of the dependence of Y(P,x) of L.

Therefore, obtain: $Y(P,x) = \dfrac{\lambda}{4\pi}\rho(L(x))\cos\alpha dx$, where the shape of function $\rho(L)$ is shown on Figure 6. Integrating the last expression over the hemisphere, obtain:

$$Y(P) = \frac{1}{4\pi} \times \lambda \times \iint_{x \in hS^2} \rho(L(P,x))\cos\varphi dx = \frac{C}{4\pi} \times \lambda \times w(P). \qquad (10)$$

The obtained expression for *Y(P)* is the desired equation (2) for *I(P)*, the only difference is in the constant factors. Clearly, this is insignificant since to compute the lighting for a given scene it is sufficient to use just some constant factor (dependent either on I_A (2) or on λ in (10)). The final remark is that usually the intensities computed using radiosity method are gamma-corrected before the actual rendering, while in our model this gamma-correction is intrinsic.

To justify the equation (5), we suppose that with the presence of light sources affects the luminance of gas in the neighborhood of patch *P*. Approximately (if light sources are relatively far from patch *P*), the intensity of the gas in the neighborhood of patch *P* can be computed using the equation (6). Therefore, we accurately account for the direct illumination and approximate the indirect light using the lit gas. Indirect illumination from the invisible light sources can be accounted by changing the function $\delta(j)$ in equation (6): $\delta(j) = 1$, if the source is visible, $\delta(j) = \beta$, $0 \le \beta \le 1$, if the source is not visible.

Definitely, the physical foundation of the obscurance illumination model is empiric, and the final justification of the usefulness of the chosen approach is that it produces nice illumination results by simulating the subtle indirect illumination effects without recoursing to the expensive methods.

5. Computing the lighting using the obscurance illumination model

As it was stated above, the obscurance coefficient is similar to integrated weighted form factors. Indeed, for a given patch Q illuminating the patch P the differential form-factor dF_{PQ} is defined as:

$$dF_{PQ} = \frac{1}{\pi r^2} \cos\varphi \cos\phi dS_Q , \tag{11}$$

where:

φ, ϕ - the angles between the line PQ and respective patch normals

dS_Q - the differential area of patch Q

r - the distance between patches

Clearly, $dx = \frac{1}{r^2} \cos\phi dS_Q$, and hence:

$$w(P) = \int_{over\,all\,visible\,patches\,Q} \rho(dist(P,Q)) dF_{PQ} \tag{12}$$

This last equation indicates the computation method for the obscurance of a given patch. To compute the obscurance, one may compute the form factors for the given patch with all the visible patches in the neighborhood of patch P using, e.g., the hemicube method, and then integrate the form factors weighted with the function $\rho(L)$.

As we noted above, the function $\rho(L)$ differs from 1 only in the range $[0..L_{max}]$. Therefore we may compute the form factors for patches only in the neighborhood of a given patch P. Practically, in our sample environments it is sufficient to take L_{max} equal to 15-25 patch sizes, while D, the diameter of the environment, is approximately 500-700 patch sizes. A slight modification of the hemicube method is needed to take into account the 'absent patches', i.e. the patches that are not found in the L_{max}-neighborhood of patch P.

The locality of the method makes it much faster than the conventional radiosity. Besides, since in obscurance illumination model it is valid that no patch is found in a given direction, the method works perfectly in partially-open environments.

6. Results and conclusions

The illumination model described in the paper has been practically implemented in a proprietary lighting tool. Our goal was to compute the illumination for the highly complex environments like the ones shown on Figure 3 and in Appendix. In such environments there can be up to 10000 polygons, so computing lighting using conventional radiosity would be too slow since it takes many iterations to set up the lights in the environment properly. The lighting data was stored in light map textures and used for real-time visualization to modulate the ordinal textures of the scene (practical issues of lightmapping are described in [Zhuko97, Zhuko98]). Even though we tuned the tool specifically for this kind of scenes, we also computed the illumination of more usual 'table and chair' scenes like the one on the figures below. Notice, there is no much difference in the general outlook in Figure 7 and Figure 8.

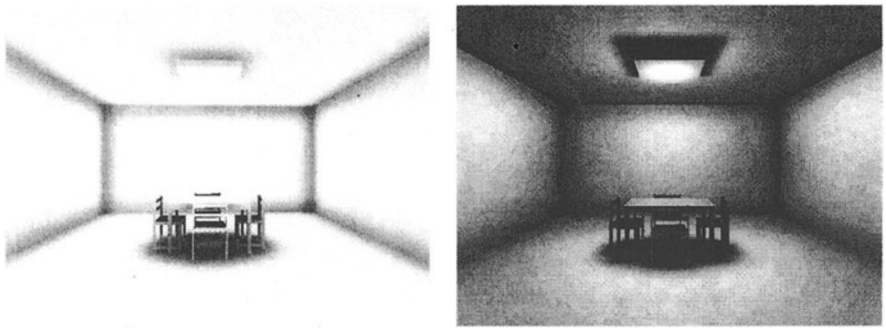

Figure 7. A 'table and chair' scene computed with pure obscurances only (left) and using the full model (equation (5)) with a point light source (right).

Figure 7 (left) was computed using the obscurances only using the equation (4)); Figure 7 (right) was computed using the full model (equation (5)) with one light source. In our computations we subdivided the scene into 14000 patches. On Pentium-166 it took less than 1 minute to compute the illumination using the illumination model proposed. The scene on Figure 8 was computed using Monte Carlo radiosity [Sbert96]. The scene was subdivided into 2000 patches and it took 10 minutes to compute it on a similar machine [Sbert98].

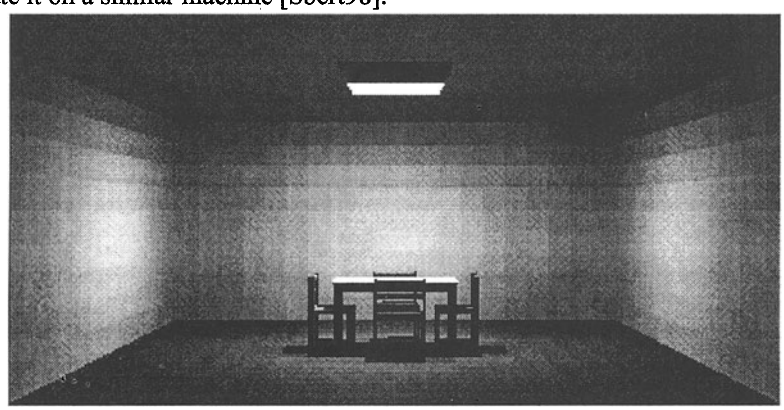

Figure 8. The same scene with distributed light source rendered using Monte-Carlo radiosity. (Scene is courtesy of Peter Shirley. Image is courtesy of Mateu Sbert, University of Girona, Spain)

In the Appendix we show some more screenshots of the scenes illuminated using the model described.

Finally, we briefly summarize the basic advantages of the proposed model:

Obscurance illumination model enables to simulate (non-constant) ambient light distribution in the environment. Besides, it makes possible to reproduce appealing and realistic images and preview scenes without explicit light source setting at all.

- The use of the suggested model enables as well to account the indirect illumination from light sources without the use of expensive radiosity method or ray tracing.
- Once the obscurance coefficients for the given scene are computed, it is easy to recompute the lighting while scene editing or for moving light sources.
- The complexity of the suggested algorithm is much less than the radiosity algorithm since only the geometry in the vicinity of a patch of interest is accounted during the computation.
- The illumination model works well in partially open environments.

Overall, obscurance illumination model can serve as a good alternative to radiosity for the applications where it is possible to sacrifice the physical accuracy of the computations, but gain in speed and ease of previewing and rendering the scenes without explicit light source setting.

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Editors' Note: see Appendix, p. 326 for colored figures of this paper