

# Irregular, unknown light sources in dynamic global illumination

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## Abstract

The goal in global illumination solutions for dynamic environments is to update a scene based on past scenes. For this difficult problem, current state of the art solutions are either not applicable, or unduly complex, when there are large changes in the illumination of unbounded number of objects. Such changes may be caused by the appearance of unexpected (at modeling time), irregular light sources.

We define a subset of dynamic environments in which new light sources may be user introduced, and implement solutions that complement existing schemes.

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## 1. Introduction

View-independent global illumination techniques are invaluable for a gamut of applications in engineering, design, education, advertisement, and entertainment. The importance of effects such as soft shadows and caustics are underscored when we use these schemes. At the same time, users have increasingly been demanding *interactive* methods to deal with *dynamic* environments.

The general problem of adding, removing, and changing objects in scenes might at first seem to flummox traditional radiosity methods since it violates the basic principle. Despite this, several early researchers [1,7] show how to compute incremental solutions by shooting corrective (possibly negative) energy to the scene affected by the environmental changes. These older solutions could not satisfy the interactive demands (Fig. 11).

Recently there has been renewed interest in both technology driven hardware solutions [9], and knowledge-based software solutions [4] using faster wavelet radiosity techniques in an attempt to satisfy these user demands. There are two cases when these solutions are satisfactory.

- For instance, there is an important subclass of dynamic problems where the geometry of the scene does not change, but only the lighting *predictably* changes. A very common situation (Fig. 1) is when users turn on (or off) switches in room. If the sudden change in lighting is caused by predictable light sources, it is possible to anticipate the shape of light source changes, and pre-process the scenes to take care of large lighting changes.
- In the second case, only localized marginal lighting changes happen such as in the creation of synthetic movies where there is not much change between frames. Unfortunately, as mentioned in Ref. [10], current techniques do not work when the lighting changes are *not* localized.

### 1.1. Our contributions

However, there are a *large* class of situations where non-localized *abrupt* changes are useful to model, or when the lighting change is unexpected. Here the *shape* and amount of unexpected lighting changes preclude any preprocessing. Examples of these are partial pulling of window blinds, closing of curtains, appearance of daylight in rooms due to the motion of parked cars, bathing of interiors as the full moon appears past overcast clouds, and effects created in operas and theaters. In such situations, current wisdom suggest the recomputing of the lighting from scratch [10] choice since the illumination of

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Fig. 1. Two snapshots from the movie 'Dunston Checks In.' Sudden changes in lighting conditions are common, and can be handled by existing incremental radiosity techniques if the geometry of the light sources are known in advance.

unbounded number of surfaces change dramatically. Our focus in this work is this situation.

Specifically, we note that the sophisticated methods of dynamic radiosity are either not applicable for reasons cited, or way too complex for rendering unexpected, irregular light sources. The key situation modeled in our work is that *users may specify the existence of a light source of any shape at run time.* (See Fig. 11.)

We provide a simple fast solution based on hierarchical radiosity (HR). Because HR scales very well (specifically linearly) as the scene density changes, or as

the illumination changes, we inherit these advantages as well. The term 'irregular' is used to indicate that the unexpected sources of light do not have to be aligned with the patches used in HR.

Fig. 2, with the accompanying caption, provides an example.

The rest of the paper is as follows. After a discussion of the previous work in Section 2, we give details of our method in Section 3. In Section 4, we give the results of our approach. We conclude with a discussion of the advantages and limitations of our work in Section 5.

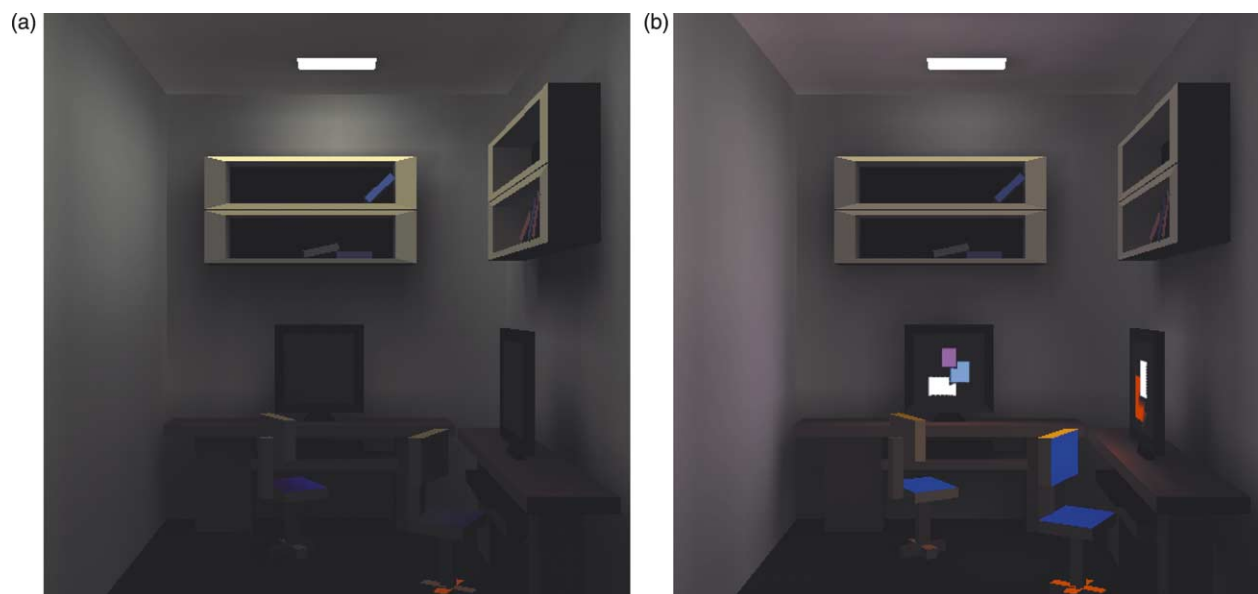


Fig. 2. Two different states of an office. The solution on the right is incrementally computed based on the illumination in the first by Algorithm AR (Section 3.1). (a) An office with two flat monitors, presumably with screen savers turned on. (Results are best viewed in color.) (b) The appearance changes because mouse motion causes the windows to break out of the screen saver mode. Note that the position of these new 'light sources' is not known apriori.

## 2. Previous work

The simplest situation involving lighting changes is when the application calls for many lighting changes in an otherwise static environment. Since the radiosity equation is linear, this solution can be obtained by anticipating the changes, and preprocessing a solution with unit light sources. In Ref. [3], lighting with well-defined finite geometries is preprocessed for design and simulation of opera lighting effects. This method is not applicable if the light sources are not defined at modeling time.

In Ref. [1], scenes involving geometry changes are rendered by shooting negative energy in progressive refinement radiosity. This solution may be used for novel light sources, by postulating a new patch of the defined geometry. It forms a basis for one of the three solutions we present in this work. Unfortunately the solution, which predates HR, is not very efficient since it essentially calls for a recomputation.

The algorithm in Ref. [6] partly resembles our effort in that HR is used as a basis, and objects are assumed to be neither created nor destroyed. Links are either ‘broken,’ promoted, or demoted based on the motion of objects. If we know a priori which objects move, then the update of these links is possible; we could then provide an incremental solution.

In Ref. [4], a sophisticated HR based solution (with clustering) is proposed. The solution replaces links in HR with shafts so that when an object moves, it is possible to identify which portions of the scene needs to be updated. More recent work on shafts include [2,11] that reduce the high memory requirements intrinsic to the method. However, all these solutions work well only when illumination changes are local. Recently an object space approach of caching prior rendering has been proposed in Ref. [12] for situations that allow for large movement of light sources. A run-time user defined light source would, however, require the use of a new patch which did not exist in earlier scenes, thereby defeating the cache.

## 3. The algorithm

For simplicity, the methods in this section assume that the source of light appears on one or more of the preexisting patches. For example, we do not consider the case of a source of light appearing out of nowhere in the middle of a room. As mentioned earlier, this enables simpler, interactive algorithms, and at the same time, provides solutions for a reasonable subset of situations in dynamic environments in global illumination. Our solutions work in the context of the HR algorithm using ‘BF refinement’ [8]. Since patches correspond to roots of quadtrees, we term the patch corresponding to the (undetermined till user specified) light source as the source quadtree  $SQ$ . As is well known, the algorithm refines user patches into subpatches and sets up a linear number of links.

There are a couple of straightforward ways of dealing with a new light source. The naive solution would be to introduce a new patch modeling the light source, and rerun the hierarchical solution, thereby introducing new links. We implemented this solution to contrast with two other solutions since this algorithm provides us with a measure of ground truth (Fig. 3).

### 3.1. Adaptive refine

The intuition behind the second solution, termed adaptive refine (AR), becomes clear if the light source matches exactly two nodes as shown in Fig. 4(a).

In the general case, the light source will intersect with some of the preexisting nodes of the HR algorithm. Since we use BF refinement, we need to further refine nodes that would not have been expanded in the original algorithm as shown in Fig. 4(b).

The pseudocode (Fig. 5) below determines precise those nodes that need to be expanded, and an example is shown.

Application of `Intersection()` results in, general speaking, the source quadtree  $Q$  becoming deeper.

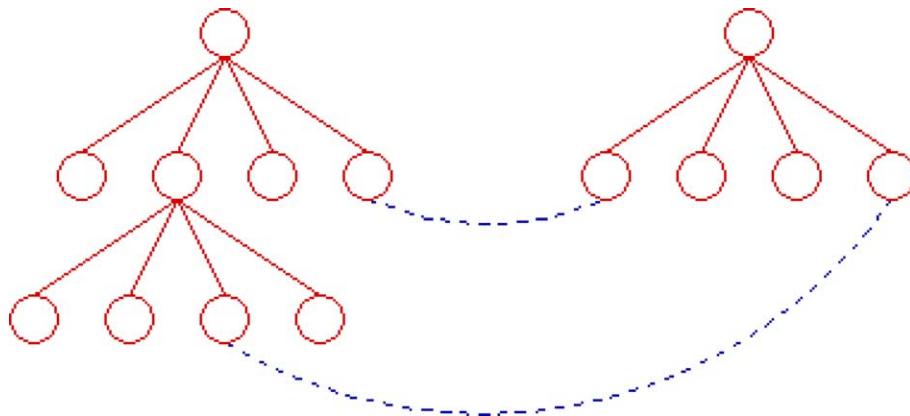


Fig. 3. The basic HR algorithm refines patches into subpatches and sets up links between nodes at various levels.

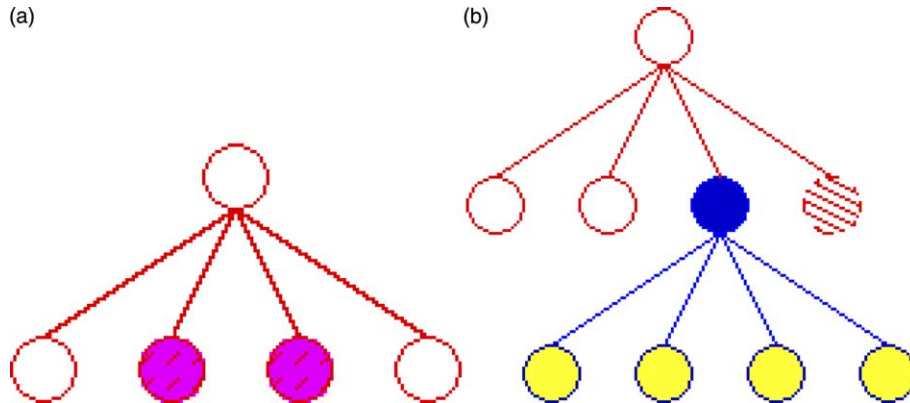


Fig. 4. The intuition behind our algorithms. (a) A contrived light source maps to exactly two nodes (shown filled) in the HR quadtree of height two. Computing the new illumination levels is straightforward. (b) The original HR algorithm terminates at height 2. Two shaded nodes intersect the light source but only one node is completely contained in the light source. Therefore the other node is further expanded.

However, patches other than the one on which the light source is presumed to lie on are not immediately affected. Nevertheless, since the basic HR algorithm using BF refinement is iterative, the net result is that both the sender

and receiver patches are ultimately impacted. The level of impact depends on how strong the source of light is, and the proximity of the receiver to the source.

### 3.2. Fractional emissivity

Although AR is fast, it can take a large amount of time if the initial scene is dense, and the input light source is highly irregular and not aligned with the patch boundaries. An even faster algorithm is possible if one accepts a coarser approximation of the light source. The idea here is to mark those portions of the HR nodes that get affected by the light source as in AR. The departure with AR arises

```

Algorithm Intersection(LightSource R, Quadtree Q) {
  if Disjoint(R,Q) then
    return NULL;
  if Contained(R,Q) then /* Q is contained in R*/
    return Q;
  else for each childi of Q do
    Intersection (R, Q.childi);
}
    
```

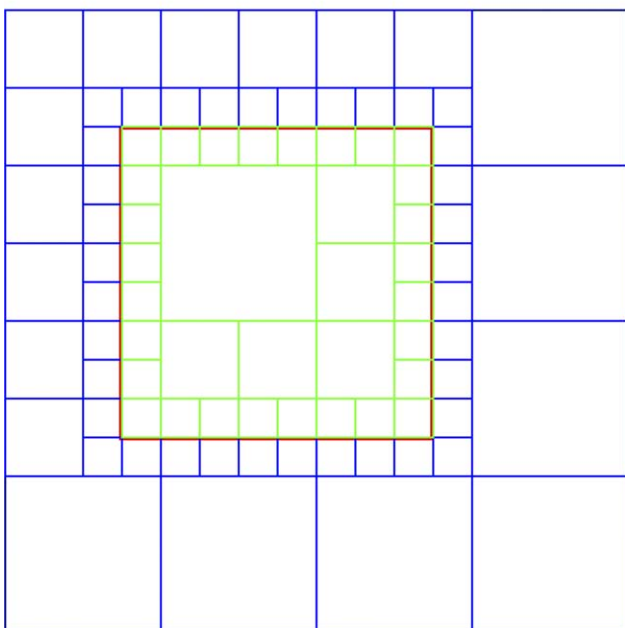


Fig. 5. Determination of nodes that need to be expanded is obtained by a fast intersection algorithm.

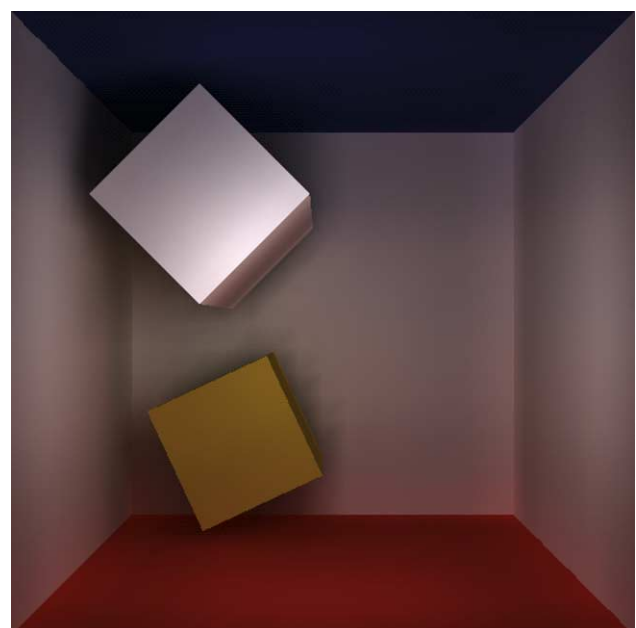


Fig. 6. A pigeon's view of the Cornell room. Only portions of the red wall (closest to this caption) appear in this view.

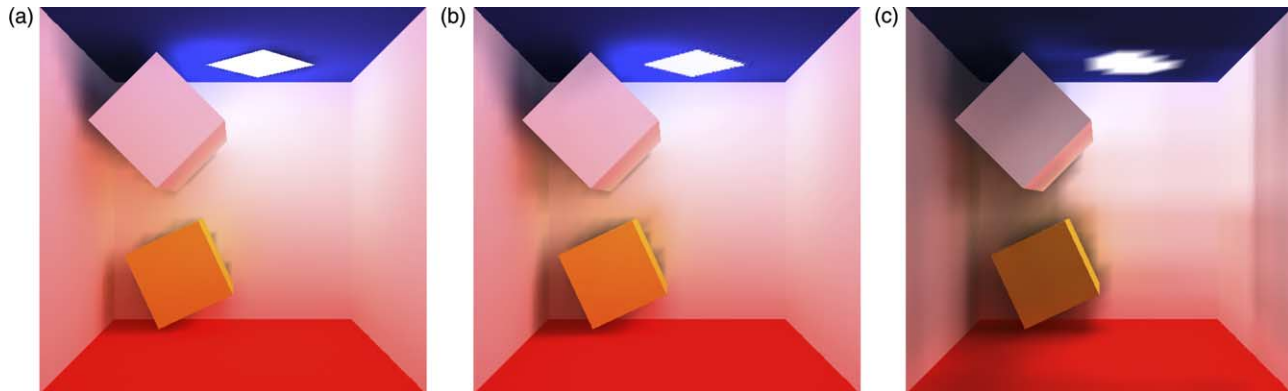


Fig. 7. Light filters through the southern wall of Fig. 6 onto the blue wall. The resulting scene is rendered incrementally in the two methods on the right. (a) The naive method (126 s). (b) Rendering using AR (3 s). (c) Rendering using FE (0.8 s).

when AR decided to further refine a node  $n$  that the HR algorithm does not refine. At this point, in the third algorithm, fractional emissivity (FE) is assigned to  $n$  based on the percentage of overlap between the light source and  $n$ . This overlap is computed using an algorithm such as Hodgman-Sutherland [5].

The three algorithms are qualitatively compared in Fig. 12. The basis for comparison is in the rendering of different scenes with varying quality factor. As can be seen, AR is comparable in quality with the naive algorithm, but runs much faster. In general, we found that FE runs only slightly faster than AR. It is

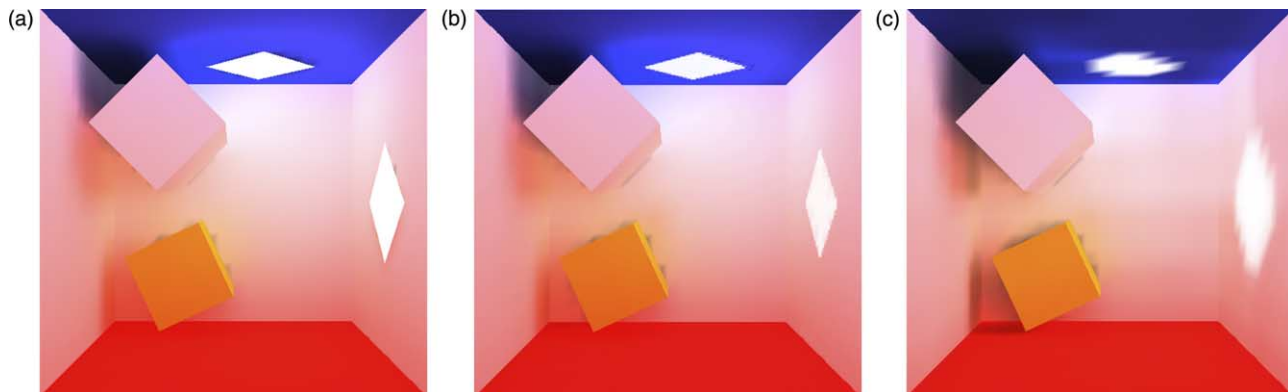


Fig. 8. A second light appears on the eastern wall. (a) The naive method (172 s). (b) Rendering using AR (4 s). (c) Rendering using FE (0.8 s).

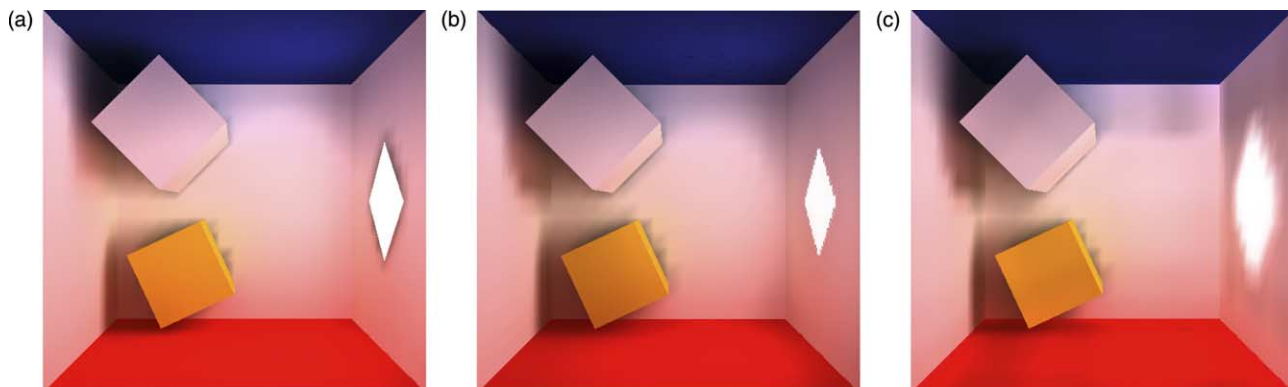


Fig. 9. The light on the blue wall disappears to reflect the passage of time. (a) The naive method (92 s). (b) Rendering using AR (1.5 s). (c) Rendering using FE (0.8 s).

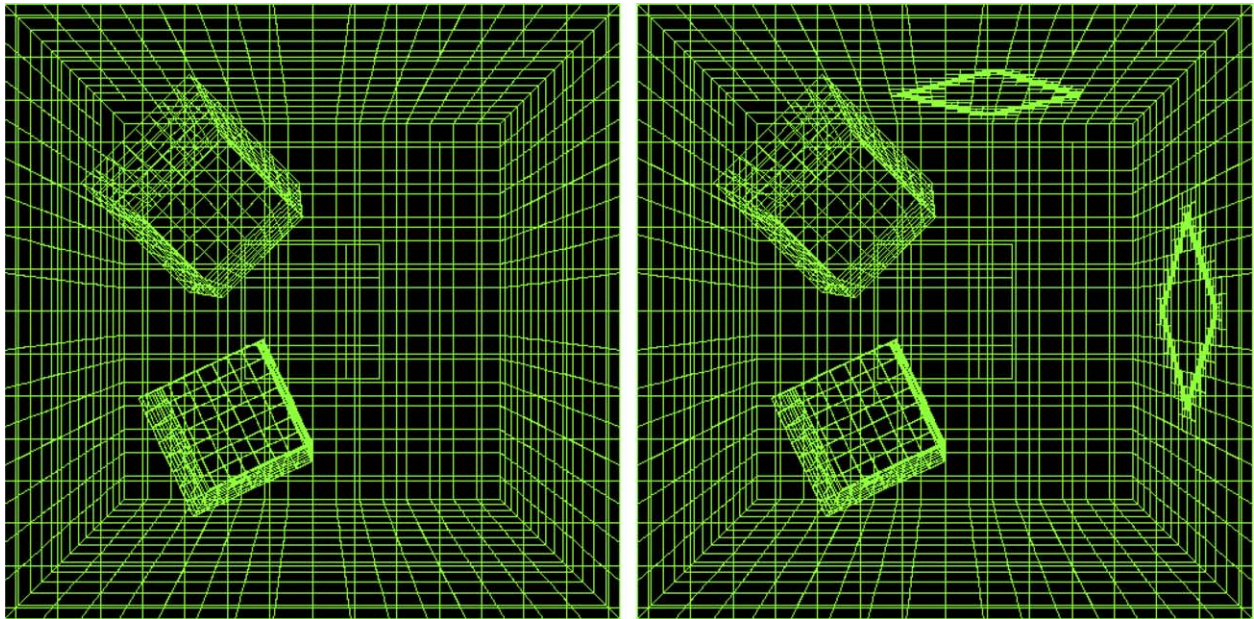


Fig. 10. A wireframe is shown to visualize how adaptive refine (appearing on the right) further refines HR.

therefore more suitable in very few, highly interactive situations.

**4. Results**

We first test our method on the Cornell room with the usual light source on the ceiling as shown in Fig. 6.

With the top view in mind, let us refer to the (blue) wall closest to the taller block as the front (or northern) wall.

The room is now lit with a quadrilateral light source (possibly through an open window) on the front wall. The results of rendering the image through the three different methods are shown in Fig. 7. Note the illumination changes (as compared to Fig. 6) in the north-east portion of

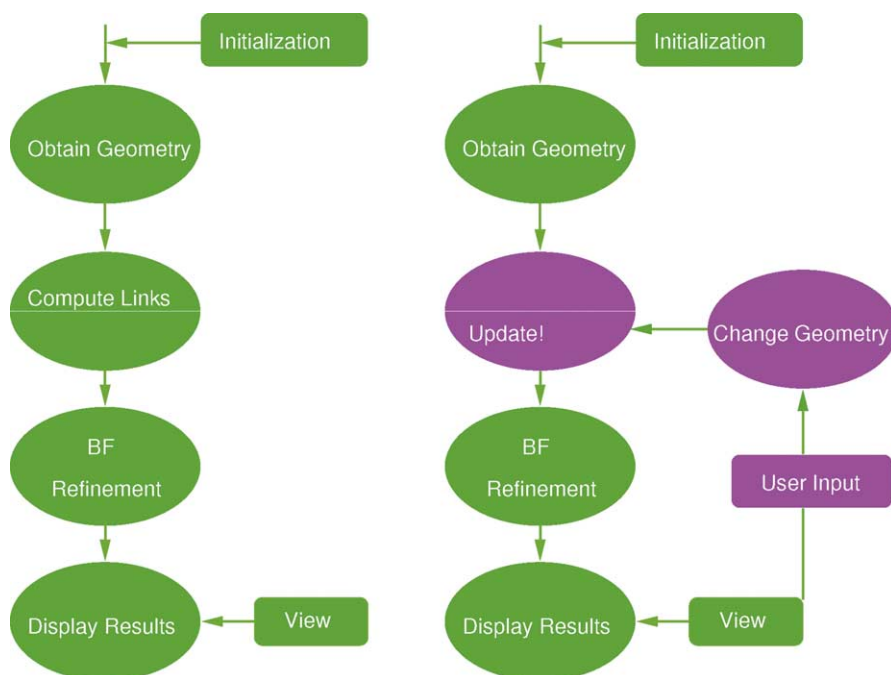


Fig. 11. The figure on the left corresponds to traditional radiosity. This context of our algorithm appears in the figure on the right.

	N	AR	
Quality ↑		AR	FE
			FE
	Speed →		

Fig. 12. Qualitative comparison of the three algorithms implemented in this work. ‘N’ denotes the naive algorithm, ‘AR’ refers to the adaptive algorithm of Section 3.1, and ‘FE’ denotes the algorithm of Section 3.2.

the room, and also the changes in the shadow in the south-west portion. Fig. 7(a) shows the image generated by the naive method which took 126.28 s, whereas the AR approach, Fig. 7(b), takes only 3.08 s. The resulting quality is comparable, both visually, and in terms of actual numbers provided by the HR method. Fig. 7(c) shows the image rendered by the FE approach which took 0.82 s. However, the quality of the image is lower than the other two approaches. All timings quoted are on a Pentium III workstation with 256 MB of RAM running Linux, and includes all overheads (see Fig. 11).

To see the flexibility of our system, we now add another light source on the right, eastern wall, and then ‘turn off’ the first light source. The resulting pictures (Figs. 8 and 9) using the three methods are shown first in Fig. 8(a)–(c), and later in Fig. 9(a)–(c). These results are best seen in color.

It is instructive to see how the refine process works. For this we include (Fig. 10) a wireframe version of Figs. 6 and 8(b). The incremental effect is clear. Finally, the incremental solution of Fig. 2 took about 3.34 s.

## 5. Concluding remarks

Modeling scenes, where lighting sources are irregular and unanticipated, form a class of dynamic environments. The location and number of objects whose lighting changes are large may be unbounded. For example, revolving police search beams during dusk and dawn may pose challenges to current sophisticated algorithms in the sense that the significant lighting change may preclude their use. Of course, lighting changes need not be sudden; we simply might be interested in generating pictures at various points of the day, possibly in computer vision experiments. Fig. 13 shows the Cornell room (presumably with a window) bathed in *irregular* light appearing through trees.

In this paper, we have considered this subclass of dynamic global illumination environments in an interactive setting (Fig. 11). We have provided a simple fast solution based on HR. It is not clear how one would solve this problem using another alternative, such as photon mapping. Our solutions are computed incrementally

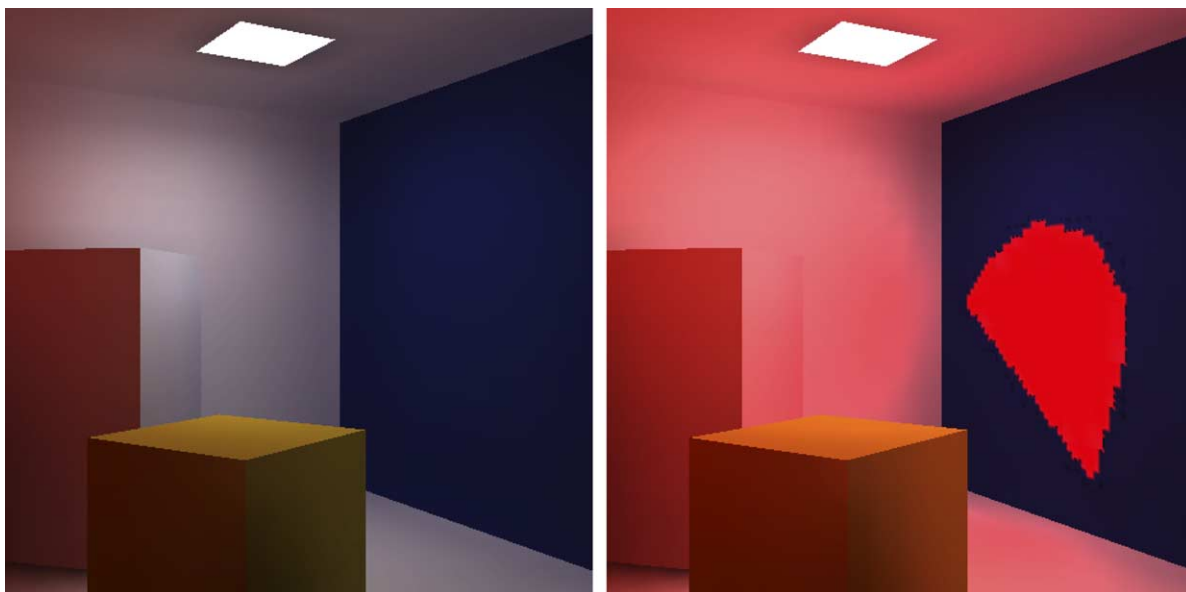


Fig. 13. The Cornell room, assumed to have a window. The figure on the left shows the standard room lit by an interior light source. At a different point in the day, the room is lit by an unexpected light source with *arbitrary* shape through the window. We would like to build a solution based on the first one, instead of starting a new solution based on a new patch.

and take a very small fraction of time compared to an algorithm that starts from scratch. We anticipate that our solution can be ‘buried’ in more sophisticated schemes (for example, Refs. [4,12]) that handle general dynamic environments.

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