Radiosity On-line: A Bibliography

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There are two basic approaches to generating photorealistic images in computer graphics. The first approach involves ray tracing techniques; the second approach is radiosity.

Radiosity is in some ways the complement of ray tracing. While ray tracing techniques excel in the rendition of point light sources, specular reflections and refraction effects, radiosity methods accurately model area light sources, diffuse reflections, color bleeding effects and realistic shadows. Together, they offer rendering capabilities beyond those available from ray tracing or radiosity alone.

The essence of ray tracing technique is the geometric ray. We model rays of light that emanate from the eye and propagate through the environment. We can create synthetic images by calculating their interaction (that is, reflection, refraction, absorption and so forth) with objects in the environment. In this sense, we can see that ray tracing models objects, or at least our perception of them, from a given viewpoint.

Radiosity offers a fundamentally different approach. Given a complex environment, we can subdivide each surface into a mesh of polygons called patches. By modeling some of these patches as emitters, we can determine the interreflections, or multiple bounces, of light within the environment on a patch-by-patch basis. From these interreflections come the indirect lighting effects, gradations and soft shadows that can impart such a dramatic sense of realism to radiosity-based images.

It has been argued that ray tracing offers view-dependent solutions, while those of radiosity are view-independent. That is, once the radiosity equation has been solved for a given environment, different views can be rendered very quickly. This, however, is a fallacy. Radiosity's view independence applies only to ideal diffuse (or Lambertian) surfaces. As Ward (1994) so eloquently reminded us, stochastic ray tracing techniques such as those used in RADIANCE are equally capable of view independence under these conditions.

Radiosity is more than this, however. Whereas ray tracing models objects, radiosity models light. That is, radiosity models light as a five-dimensional scalar "photic field" that permeates any luminous environment (Moon and Spencer 1981). This field can be thought of as an infinite number of rays, each with its own measurable photometric brightness (or, more properly, luminance) at each point in space along its length. The objects in the environment become little more than the field's boundary conditions.

Light as a five-dimensional scalar field? In terms of photorealistic images, this concept may have little to recommend it. Nevertheless, it is important in the broader context of computer graphics applications. Glassner (1994) noted that "computer-generated images are used today in two distinct ways, characterized by whether the intended receiver of the work is a person or a machine." His "machine" is a software program that computes the distribution of illumination in an environment, a design and analysis tool for architects and lighting designers. The success of this program is measured in the accuracy of its predictions rather than the aesthetics of any rendered image.

Radiosity provides a useful solution to this problem. In modeling the photic field, it allows us to predict any photometric quantity at any point within an environment (Yamauti 1932, Ashdown 1993). This includes not only defined surfaces, but every point in space between the objects. As such, radiosity becomes an almost ideal lighting design tool—a fact that has been long known to the illumination engineering community.

Radiosity is often thought of as a relatively recent innovation. After all, it was introduced by Goral et al. (1984), who derived it from a thermal engineering technique of the same name (e.g., Hottel and Sarofim 1967). Change the name to radiative transfer theory, however, and it appears in the illumination engineering literature as early as Yamauti (1926) and Buckley (1927). Yamauti's seminal paper presented radiosity in terms of Fredholm integrals of the second kind, a mathematical formalism that did not appear in the computer graphics radiosity literature until its rediscovery by Heckbert (1991).

Yamauti's discussion was mostly theoretical. However, it was quickly translated into a formal engineering tool by H. H. Higbie, who published it as a practical technique in his 1934 book, *Lighting Calculations*. Unfortunately, it was an idea before its time. With only hand-cranked calculators to assist them, this precursor to today's radiosity algorithms was not widely practiced by illumination engineers.

One exception was the work done by Moon and Spencer in the 1940s. They used Higbie's technique (which they called the interreflection method) to study lighting in empty rooms (Moon and Spencer 1946). Credit for the first photorealistic images created using radiosity methods must go to Moon and Spencer—they exhibited synthetic photographs of empty rooms with luminous ceilings at the 1946 National Technical Conference of the Illuminating Engineering Society of North America (O'Brien and Howard 1959). They calculated the luminance of each surface patch by hand, cut out paper squares from Munsell color charts and pasted them together to form their images. These were then photographed for presentation, and later reproduced in Moon and Spencer (1948).

Historical trivia? Undoubtedly! Nevertheless, it illustrates a crucial point: it is rare to find a field of

research that does not have important antecedents (and occasional anecdotes) of one sort or another in other fields. For radiosity, these are papers and books from such diverse fields as illumination and thermal engineering, photometry and radiometry, computer vision, radar research, finite element analysis, stellar atmospheric modeling and nuclear engineering. They represent an invaluable resource, both for our understanding of radiosity in its broadest context and as a source of novel ideas for future research.

Our community has been investigating radiosity as a computer graphics technique for barely a decade. True, there have been many important advances—progressive refinement radiosity (Cohen et al 1988), hierarchical radiosity (Hanrahan et al 1991), accelerated convergence techniques (Shao and Badler 1993) and stochastic radiosity (Neumann et al 1994) are a few that come to mind. However, some of these advances have been in fact independent rediscoveries of known algorithms.

Görtler and Cohen (1993), for example, found that the progressive refinement radiosity algorithm (Cohen et al 1988) is actually a variant of Southwell iteration (e.g., Gastinel 1970). In other words, what was previously an obscure iterative solution technique for matrices has become perhaps the most important algorithm in radiosity. We have to ask ourselves, what else are we missing? Better still, what is there in the literature that we can possibly synthesize into new and more powerful radiosity methods?

Central to this issue is a comprehensive bibliography of radiosity-related papers and books. To be useful, it must be widely available, freely distributed and constantly updated. To this end, two bibliographies have been independently developed. One of us prepared an extensive bibliography for a programmer's guide to radiosity (Ashdown 1994), while the other (Haines) developed an on-line bibliography as a public service for the computer graphics community.

We recently merged our efforts, which are now available on-line. Our bibliography currently contains over 500 radiosity-related references. It will be updated in December 1994, at which time it will be merged with a global illumination biography contributed by Paul Heckbert to include over 700 references.

Whether you are investigating new radiosity methods or looking for ideas to improve existing algorithms, there is much to be gained from a careful review of the literature. We hope that our on-line bibliography will prove to be as useful to you as it has been for us. In return for its use, we ask only one small favor.....if you find something interesting that is not in our bibliography, please let us know! It is, after all, a community effort.

The bibliography is available via:

- ftp at hobbes.lbl.gov as /pub/doc/RadBib94.Z
- siggraph.org in the database "biblio" through the "biblook" program
- World Wide Web at the URL http://siggraph.org/library/bibliography/bibliography.html

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Ashdown has 11 years experience in electrical engineering and lighting design and 14 years experience in telecommunications software engineering, computer graphics and image processing. He has written 28 articles, six academic papers and two books, and is a member of ACM SIGGRAPH, IEEE Computer Graphics Society, Eurographics and the Illuminating Engineering Society of North America.

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