Famous last words:

Once and Future Graphics Pioneer

by B.J. Novitski

In the glitzy world of computer-generated visualizations that dominate movies and magazines today, it's easy to take for granted the photographic quality that architects are able to give their renderings of proposed buildings.

But behind the scenes, there have been have been four decades of grueling, dedicated, and inspired research to make possible these synthetic images that are indistinguishable from photographs.

One of the world's leading laboratories in this field is the Program of Computer Graphics (PCG) at Cornell University, in Ithaca, New York. Director Donald P. Greenberg has led the program since its founding in 1974. Greenberg, his staff, and students have developed the theoretical basis for many of the practical applications that architects now use routinely.

For example, research performed at Cornell's PCG led to the development of Lightscape, a rendering program capable of creating very realistic lighting effects by calculating the precise amount of light reflected from surfaces and materials within a scene.

A Unique Research Program

Greenberg was educated in architecture and engineering at Cornell and Columbia universities. As a consulting engineer with Severud Associates, an architecture and engineering firm, he was involved with the design of the St. Louis Arch, Madison Square Garden, and other projects.

Today, Cornell student Ivan Perez Rossello's computer graphic of an Indian Culture Museum, with a view out to the desert landscape of Chaco Canyon, New Mexico, is virtually indistinguishable from a photograph.
Image: Program of Computer Graphics

Then and now. In 1971, when computer imagery was virtually unheard of in architectural circles, researchers at Cornell University created an image of the Johnson Art Museum, designed by I. M. Pei.
Image: Program of Computer Graphics

Click on thumbnail images

Once and Future Graphics Pioneer

(continued)

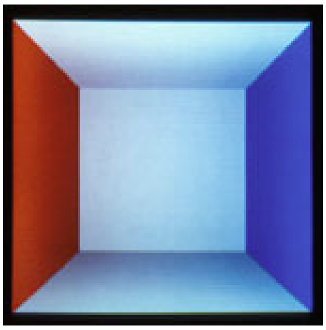
During the 1960s, Greenberg became intrigued with the design potential of computers but was impatient with the numeric output provided by engineering applications. His efforts to write software to display results graphically led to the establishment of the multidisciplinary Program of Computer Graphics, with significant funding from the National Science Foundation.

Today, the research center is still funded by NSF and also by Intel, Hewlett-Packard, and Autodesk. Because the PCG is independent of any one academic department, its students and faculty enjoy an unusual opportunity for multidisciplinary research.

Most individuals are from the departments of architecture and computer science. Others have come from the fields of engineering, art, perception psychology, and theater arts. This mix results in a rich research environment that values human perception and the aesthetics of light as much as physics and precision computation.

Currently, research performed at PCG focuses on three major areas:

- improving the user interfaces for architectural applications to make them more suitable for designers; - simulating the behavior of light in space and understanding the human visual perception system to refine the rendering

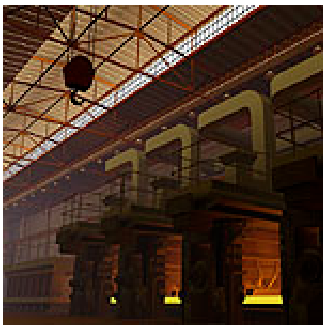


In 1984, "The Cornell Box," by Cindy Goral, Kenneth Torrance, and Donald Greenberg made history as the first radiosity image. Computations for this simple environment were measured in tens of minutes.
Image: Program of Computer Graphics

In 1985, Michael Cohen's radiosity image of "The Magritte Studio" was computed using the hemi-cube algorithm. It took fours hours on a VAX 11/780.
Image: Program of Computer Graphics

algorithms (computational procedures); and
- developing methods for improving image capture and the quality of image-based rendering.

For the architecture profession specifically, the PCG is concentrating on developing conceptual design tools, enabling architects to design in context, and enabling collaboration over the Internet.



IN 1987, "Steel Factory," by Stuart Feldman, Michael Cohen, and John Wallace was the lab's first complex radiosity image. The model consisted of 30,000 patches. The radiosity solution was followed by a post-process radiosity gathering algorithm requiring another 190 hours of computation. Image: Program of Computer Graphics

Rethinking the Medium

In Greenberg's opinion, the typical user interface for architectural software, with the familiar mouse and monitor, is badly suited to the hand-eye collaboration that characterizes architectural design. He and research associate, visiting professor Moreno Piccolotto are developing a system that works with a drawing-board sized device from Toronto-based Input Technologies Inc., which functions as both sketch pad and display device.

Moreno Piccolotto demonstrates sketching on the ITI VisionMaker PS digital drafting table. The sketch routines, conceived in 1998 by Donald Greenberg, Piccolotto, and Michael Malone, operate at interactive rates. Photo: Program of Computer Graphics

The equipment consists of a transparent digitizing surface, a cordless pen, and a high-resolution, rear-projection display, driven by a powerful microprocessor (or several working in parallel). Using this device, designers can sketch comfortably with the pen on the large, gently tilted surface.

But unlike with conventional 2D paint software, the plane on which the sketch first appears can be rotated and navigated in three dimensions and placed into an underlying 3D scene.

The system can also enable two or more designers to work on the same sketch collaboratively on the Internet. At $55,000 per unit, this equipment is beyond the budgets of many architects, but already experiments are being conducted with $3000 Wacom tablets and hand-held devices such as the Palm.

Sketching on the digital drafting table can be

The software used in this system is under development and is based on work done by Piccolotto and Michael Malone, now a software developer at Autodesk, while they were graduate students at Cornell. The software is unique in its ability to move smoothly between the realms of rough sketch, precision rendering, and real-time walkthroughs.

The ability to sketch naturally and create accurate architectural drawings as well as 3D models connects the art of design directly with the science of architectural evaluation and development. The PCG is collaborating on a prototype with a commercial software developer and plans call for a program to be available for public use in a few years.

Greenberg notes, "We make tools for a profession where the designers already know how to draw, think spatially, conceive of designs in three-space, and have great appreciation for light. If we are successful, the word 'computer' will disappear from our jargon and we will only be providing, in an electronic way, the opportunity for architects to express their design ideas."

Physics Meets Art

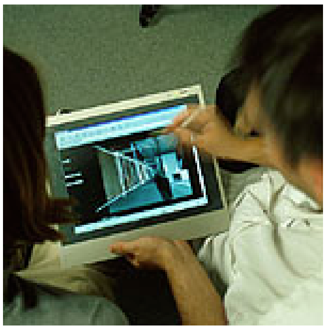
In the PCG's second major research area, Greenberg and his colleagues are studying the behavior of light to improve the algorithms used to generate 3D renderings. The well funded light measurement laboratory at the PCG is one of the best equipped in academia.

Just as acoustical engineers study sound in a theater at a variety of frequencies, researchers here study the physics of light at the wavelength level. No other architectural research lab in the world is studying light at this level of precision.

Cornell's lab, under the direction of mechanical engineering professor Kenneth Torrance, has elaborate instrumentation to measure light within physical models as it reflects from surfaces and moves through various media such as air and glass. These measurements are then compared to the simulated light calculated by existing algorithms, which are then further refined according to the real world models. As a result, the software's ability to imitate visible reality increases in precision.

However, unlike a physicist's approach to this study, the PCG lab also employs perceptual psychologists to determine how and where

superimposed on a projected radiosity image of a virtual space. The sketch's 2D plane can then be manipulated in the same 3D space as the underlying perspective.
Image: Program of Computer Graphics



The sketching routines are also being implemented on a relatively low-cost WACOM PL-400 tablet.
Photo: Program of Computer Graphics

In 1989, the "Stair Tower, Rhodes Hall, Cornell University," by Keith Howie and Ben Trumbore, was rendered using distributed ray-tracing to create soft shadows. It took one hour to compute on eight HP835 workstations.
Image: Program of Computer Graphics

mathematical improvements in rendering calculations affect the communication of meaningful visual information to the human eye and brain. When the improvement in precision is not perceptible, the researchers can modify the software to maximize speed without detracting from the realism of the computer models.

In 1993, "The Green Room," by Dani Lischinski and Filippo Tampieri, was computed using discontinuity meshing so that accurate radiosity solutions could be obtained at shadow edges. Total rendering time: 42 minutes on a single HP720 workstation.
Image: Program of Computer Graphics

Click on thumbnail images
to view full-size pictures.

Precision in light simulation, as in Lightscape, is important because it gives predictive credibility to the resulting renderings. For example, if an architect models an interior space that is supposed to be illuminated by a clerestory, a precise rendering will show whether the space does indeed receive enough light with that window configuration and orientation. If the space looks too dark, the architect using conventional renderers could simply modify the software settings to make the model look brighter.

With a physically precise simulation, the architect must adjust the window size, shape, or the position of the glazing or the color or reflectivity of the interior surfaces to improve the quality of light in the space. In other words, the problem won't be solved until the architectural elements are correctly designed.

In conventional rendering packages, light is often simulated by the "ray-tracing" method. This works best with direct lighting and highly reflective materials. Another method, "radiosity," works best with indirect lighting and diffuse surfaces.

The simulation methods currently under development at Cornell combine the advantages of both ray-tracing and radiosity to produce the most realistic possible rendition of a lighted scene. Even with today's best hardware, these computation-intensive renderings are time-consuming.

Given the pace of technology advances in hardware and software, Greenberg and his fellow researchers believe that in just a few years they will be able to generate high-resolution, precisely predictive images at a rate sufficient for real-time animation, that is, 30 frames per second.

Looking Forward to the Past

"It is fascinating to ponder the implications of exponential digital growth. In a world of infinite bandwidth, where processing, storage, and memory are essentially free, what does an architect do?

"With display devices limited only by our own visual acuity, we can create virtual worlds that are physically accurate and perceptually indistinguishable from real world scenes. Data for these predictive models, including all geometry, materials, and lighting characteristics, will be easily obtainable over the Internet, provided by manufacturers selling their wares.

"But we still need our design tools! Ones that are not restrictive and are easy to use and very comfortable. That allow me to create. In a sense, I want to go back to where I started, with pen and ink and yellow trace. Where I am free to compose in silence or to classical music or alone with nature in the outdoors. Where I am free and yet connected and able to digitally doodle and sketch. The electronic future may rapidly be approaching the potential of the environments of the past."

—Donald P. Greenberg

At the PCG, the combination of interface design, research into the physics of light, and pedagogical work demonstrates the balance with which Cornell is approaching architectural applications The PCG is improving the fit between traditional processes and new technologies.

This article will continue next week with more about this research, a peek into an undergraduate design studio, and a look back at the Cornell legacy.

B.J. Novitski is managing editor for ArchitectureWeek and author of [Rendering Real and Imagined Buildings](#).

This article first appeared in Architectural Record, June, 2000.

Page Page

Send this to a friend Subscribe Contribute Advertise Privacy Comments

GREAT BUILDINGS | DISCUSSION | SCRAPBOOK | COMMUNITY | BOOKS | FREE 3D | ARTIFICE | SEARCH