New Graphics Program Debuts in Concert Hall

By simulating sound in visual form two Cornell computer scientists are helping design acoustically perfect concert halls

ON A COMPUTER DISPLAY TERMINAL there appears a wire-frame rendition of the interior of Boston Symphony Hall—and with the touch of a key, it comes alive. A simulated sound lets loose from center stage, billowing outward on the screen in bold colors. First it expands as a simple sphere. Then, as reflections multiply from the walls, from the ceiling, from the balconies, it moves in ever more complex, subtly hued wave forms. In the end, only a few colorless "dead" spots pinpoint those areas without sound.

But then, this is what New England concert goers have known all along: Boston Symphony Hall is a superb example of acoustic design.

Designing concert halls this good could become far easier if Cornell University graphics researcher Donald Greenberg and his graduate student Adam Stettner have anything to say about it. Their new graphics program, which they introduced this past August at a national meeting of the Association of Computing Machinery's Special Interest Group in Graphics (SIGGRAPH), is the first that tries to capture the subjective experience of musical sound in pictures.

"We can blast millions of [sound] rays around the room," says Stettner. "We can see how each single sound travels all over the place and we can see it in steps of 1 millisecond, which is a finer resolution than what the ear perceives."

Indeed, he says, the program promises to give acoustic designers the same kind of computer-aided design tools that their more technical counterparts have long enjoyed in such fields as automobile manufacturing. What happens, say, to musical clarity if the walls of Boston Symphony Hall are changed from what they are now—plaster over terra cotta tiles—to fabric or wood? What happens to the spatial "presence" of the sound if the slope of the ceiling is changed or if the balconies are extended? The answers can be had with a few keystrokes.

Some such system is sorely needed, says Greenberg, who has long been a pioneer in applying computer graphics to another aesthetic discipline, architecture. Until now, he says, acoustic designers have typically made judgments based on experiments with scale models of concert halls, using light waves to give a crude simulation of sound travel. Such models are clumsy, imprecise, and costly. They can follow only a single sound wave at a time, whereas a computer can simultaneously follow thousands.

Says Bob Essert, a consultant with Artec Inc., a New York City firm that specializes in acoustics for theaters and concert halls, "To designers, the visual aspect is important. We need tools that allow us to both hear and visualize acoustic data."

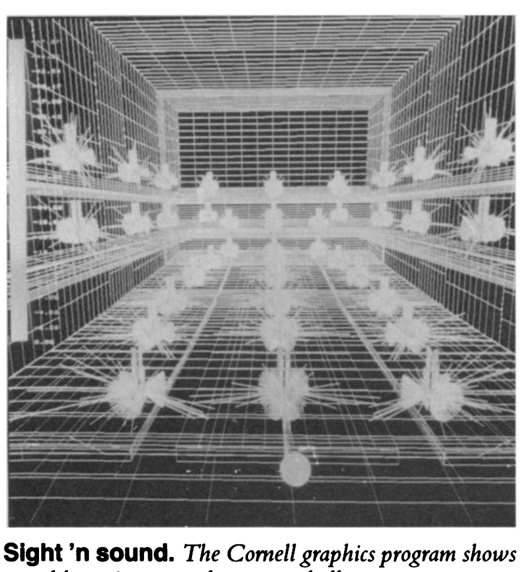
Obviously, says Stettner, that tool is computer graphics. "[Computer graphics has taken us] from the position where you have numbers, and then have some more numbers, to the visualization of quantitative data over time," he says.

In implementing their program, Greenberg and Stettner have adapted the standard computer graphics technique of ray tracing, in which the computer follows the paths of a myriad individual rays of light through the simulated volume. Their modified procedure takes into account a sound ray's slower propagation speed, longer wavelength, and higher rate of energy transfer to the surrounding environment. Thus, a single pulse or "point of sound" is modeled as a system where rays emanate outward in all directions. When a ray hits a surface, the computer counts it as being absorbed or reflected, depending on the physical properties of the surface material. Each secondary reflected ray then acts as a new sound source, and the calculation is repeated.

Just as in standard ray tracing, the computation needed to follow all sound waves in all directions from all sources is prohibitive. So Greenberg and Stettner use the standard trick: they place simulated "ears" or receivers here and there in the concert hall—in effect, a hypothetical audience—and then compute only the rays that actually reach a given ear.

For each ear, the computer then probes three qualities of sound: loudness, clarity and definition, and spatial impression. Clarity and definition are a function of decay characteristics and reflected energy. If there is too much early sound, the sounds of music or speech are blended and blurred. If there is too little, the sound is overwhelmed by late, reflected sound. Clarity is then lost to echoes. Spatial impression measures whether a listener is immersed in sound. This is a function of the fraction of sound reaching the ear laterally, rather than from the stage.

To make all this information user friendly, Stettner and Greenberg illustrate these sound qualities with a system of icons. For example, to reveal where sound was coming from for each simulated ear, Greenberg and Stettner used so-called "soundrose diagrams," which are arrays of lines emanating from a single point. The length and color of each line depicts the strength of sound from a given direction. Spatial impression is visualized by a cone emanating from the ear. And clarity is illustrated by an L-shaped icon. The width of the top of the L denotes late arriving sound and the width of the bottom early arriving sound.



Sight 'n sound. *The Cornell graphics program shows sound bouncing around a concert hall.*

Greenberg and Stettner are the first to admit that this fledging computer graphics system is not a finished product. First, it models single, impulse sounds, not continuous sound. Second, it approximates sound as a set of rays moving in straight lines, when in fact sound is a wave that can diffract around obstacles. Finally, the model follows secondary reflected rays but not secondary transmitted rays.

Greenberg, however, is optimistic that these factors may soon be incorporated into the program. "In 5 years, the computer power needed to accomplish this will be available," he says.

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